VOL. 2 No. 3 MARCH 1937

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, HOLLAND

ELECTROLYTIC CONDENSERS

By W. CH. VAN GEEL and A. CLAASSEN.

Summary. This article discusses the characteristics of electrolytic condensers and outlines the principles of their operation. Different types of electrolytic condenser for a variety of duties are described.

Introduction

It has been known for several decades that various metals, such as aluminium, tantalum, niobium, zirconium and titanium, can be coated with an oxide film by electrolytic means. This may be done by introducing the metal into a suitable electrolyte, for instance aluminium in a sodium phosphate solution, and passing a current through it, the metal forming the positive pole of the circuit *(fig. 1)*. Oxygen is evolved at this pole and oxidises the metal.

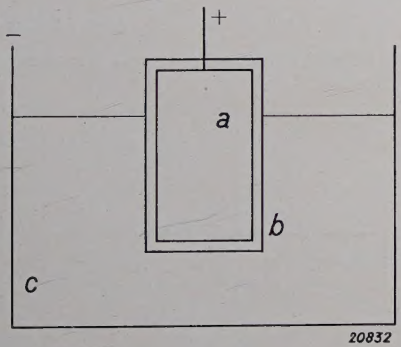


Fig. 1. Diagrammatic construction of an electrolytic condenser. *a* is the aluminium electrode, *b* the separating film of aluminium oxide, and *c* the electrolyte.

The thin film of oxide (Al_2O_3) produced on aluminium offers a very high resistance to the further passage of the current, whose intensity therefore diminishes. If the applied voltage is kept constant the current through the system after a time tends towards a certain minimum value, termed the dissipating current. A cell of this type with aluminium as the positive electrode and an electrolyte as negative electrode can be used as a condenser, the oxide film separating them acting as a very thin dielectric and thus making the resulting capacity comparatively high.

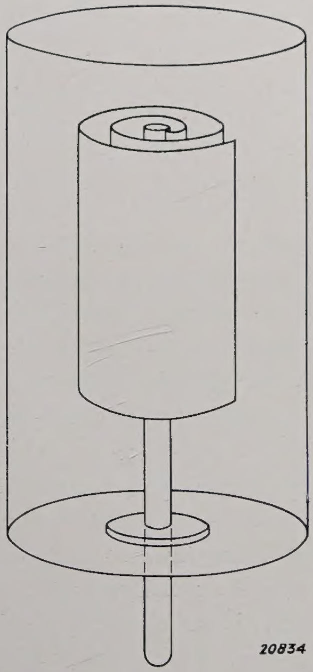


Fig. 2. Electrolytic condenser in which one of the electrodes consists of a spirally-coiled aluminium strip.

In the past it has not been found possible to reduce the dissipating current to such a low value that the heat evolved in the electrolyte could be neglected. The heat evolved was for instance 2 watts with a condenser containing approximately 50 c.c. of electrolyte, and through which a dissipating current of 0.01 A flowed at a potential difference of 200 volts. This signified the evolution of approximately 0.5 cal of heat per sec with a thermal capacity of 50 cals per degree, so that the temperature of a condenser of this construction was raised by about $^1/_2$ degree per minute.

Only after the development of radio technology and as a result of researches in various industrial laboratories were suitable means discovered for sufficiently reducing the above-mentioned dissipating current, e.g. to below 1 mA.

About 1930 electrolytic condensers were introduced for radio purposes. These consisted of an aluminium plate of suitable shape which was covered with a very thin film of aluminium oxide. The aluminium electrode was surrounded by an electrolyte, usually boric acid with some added borate, and the complete condenser enclosed in a small container *(fig. 2)*.

Characteristics of the Electrolytic Condenser

The different characteristics of the electrolytic condenser will first be reviewed.

The electrolytic condenser has a high capacity. The thickness d of the oxide film coating the aluminium is very thin (approximately 10^{-5} cm), and the dielectric constant k of the Al_2O_3 produced is high (about 10). Calculating the capacity c per sq. cm from these data, we get:

$$c = \frac{k}{4\,\pi\,d} = \frac{10}{12.6 \cdot 10^{-5}} = 8 \cdot 10^4 \text{ cm.}$$

For an aluminium electrode of 100 sq. cm surface a capacity of already approximately 8 μF can thus be obtained. More detailed reference will be made below to the extent the thickness d of the oxide film depends on the potential employed when forming the condenser, i.e. when producing the oxide film.

The electrolytic condenser can only be employed with a flow of current in one direction. The aluminium electrode must always be connected to the positive side of the applied voltage, and the body of the condenser, i.e. the electrolyte, must therefore always be negative. With current flowing through the condenser in this direction, the current intensity is small; it appears as if the condenser has a slight leak and as if a high resistance were connected in parallel with the condenser. This resistance is determined by the potential. If the direction of current flow is reversed, a strong current will flow through the condenser and the latter becomes useless as such.

It is thus seen that the system exhibits the characteristics of a rectifier, and the condenser does not then differ in any way from the well-known electrolytic rectifier.

As already indicated the condenser coatings consist of aluminium and electrolyte. The specific resistance of an electrolyte is, however, high as compared with that of metals (of the order of 100 ohms per cm). The condenser coating composed of electrolyte has therefore an appreciable resistance which is in series with the condenser.

If the potential difference applied to an ordinary type of condenser, for instance a mica condenser, is progressively raised a puncturing of the dielectric will result. What happens with an electrolytic condenser when the potential difference is similarly increased? If this difference between the aluminium and the electrolyte is steadily raised, a sparkover will be initiated between them at a certain voltage. The dissipating current, which already increased during the stepping up of the voltage, commences to rise much more rapidly when sparking begins. This sparking is analogous to the breakdown of the dielectric in an ordinary condenser, but with the fundamental difference that the flashover does not have destructive results in the case of the electrolytic condenser. The resulting disturbance of the dielectric is in fact instantaneously eliminated by the oxygen which is simultaneously evolved by the dissipating current.

Fig. 3 shows the diagrammatic circuits of an electrolytic condenser. C is a condenser of the same capacity as the electrolytic condenser. The condenser plate a represents the aluminium electrode, the dielectric O the film of aluminium oxide. b is the electrolyte whose resistance R is in series with the condenser. Between the condenser plates a and b there is a resistance r corresponding to the dissipating current and which diminishes with rising voltage.

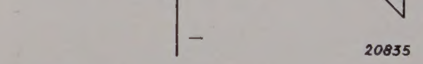


Fig. 3. Diagrammatic circuit of the electrolytic condenser. a is the aluminium electrode, o the oxide-film dielectric of the condenser C, and b the other electrode composed of electrolyte. r is the resistance of the separating layer in parallel with the capacity C; R denotes the resistance of the electrolyte in series with the condenser C.

As a rule the electrolytic condenser is employed in circuits in which a comparatively low alternating current is superimposed on the unidirectional current.

When considering this alternating current the resistance r can be neglected. The series resistance R is composed of the resistance of the electrolyte which is governed by the frequency, and a resistance which we may term the loss resistance in the oxide film. The losses in the oxide film increase with the frequency, the tangent of the phase difference of the oxide film (the resistance of the electrolyte thus being neglected) varying from approximately 2 per cent at 50 cycles to approximately 6 per cent at 1000 cycles. The capacity itself is practically independent of the frequency, and in the band from 50 to 1000 cycles it does not alter by more than 5 per cent.

Explanation of Electrolytic Rectification

The difference in current transmissibility through the system Al — Al oxide film — electrolyte in the two directions may be accounted for as follows: We have already seen that the oxide film is very thin, being of the order of 10^{-5} cm, so that if a potential difference of 100 volts is applied between the aluminium and the electrolyte, the field strength in the dielectric will be about 10^7 volts per cm. With such high field intensities, a "cold emission" always takes place, i.e. the negative electrode emits electrons.

Consider now two plane metal electrodes between which the field intensity F is so high that the negative electrode emits electrons; it is then found that the electron current i can be represented by an equation of the form:

$$i = AF^2 e^{-\frac{B}{F}}$$

where A and B are constants of the materials.

Assume that the plate a emits electrons more easily than plate b. This signifies that when an alternating voltage is applied the current passes through with greater facility in one half wave than in the other half, the greater current flowing when the plate more susceptible to electronic emission constitutes the negative pole.

To rectify a current a thin layer of insulation is therefore necessary and must be bounded by two substances capable of emitting electrons to very different degrees. If the substance which emits electrons the more easily is made negative, a higher current will flow than when it is positive.

Substances are indeed known which emit electrons with different facilities and intensities; metals emit electrons easily, and semi-conductors and electrolytes emit them with difficulty. The electrons in the electrolyte are in fact not free but are linked to ions, although the powerful field obtaining can detach the electrons from the ions and transfer them to the separating layer.

It is thus seen why the electrolytic condenser must always be connected up in such a way that the electrolyte is the negative pole, for then only will a weak dissipating current flow through the condenser. It would be most desirable to have no dissipating current at all, but as we shall see later this is unavoidable. It also follows from the above that the dissipating current will be the lower, the smaller the number of ions present in the electrolyte, i.e. the less current it conducts.

Electrolytes with a high specific resistance actually exhibit low dissipating currents, but these electrolytes have the drawback that the resistance R *(fig. 4)* in series with the condenser is made very great.

A compromise therefore becomes imperative, and consists in fixing the permissible series resistance R and tolerating the corresponding dissipating current. Fortunately in this way very low dissipating currents (less than 1 mA for 450 volts at several μF) have been realised.

It is now evident why it is impossible to use a metal as a second electrode in place of the electrolyte. In such case the separating layer (aluminium oxide film) would be bounded by two substances which emit electrons with almost the same facility, so that a high current would flow in both directions and the condenser be of no practical value. Moreover a breakdown of the dielectric would occur already at low voltages. The specified polarity and the use of an electrolyte are therefore indispensable requisites.

Condensers for Different Voltage Ratings

We have already seen that the dissipating current is generated because the electrolyte is also able to emit electrons when a powerful electric field is applied to it, such electrons migrating through the oxide film to the aluminium. This current is determined by the field strength. If in condensers made of the same materials the dissipating currents are the same at equal potential differences, it may be concluded that the oxide films are of the same thickness. The field intensity is then equal to:

$$F = \frac{\text{applied voltage}}{\text{thickness of separating layer}} = \frac{V}{d}.$$

If an aluminium electrode is oxidised in an electrolyte and a specific potential difference V_1 is applied, then as already indicated at the outset the current through the electrolyte will steadily diminish. At a certain small terminal value i_1 of this current, the oxidation process may be regarded as having terminated. If now a second aluminium electrode with the same dimensions is placed in the same electrolyte and a potential difference V_2, which is double V_1, is applied, and we wait until the dissipating current has attained the same final value i_1, it may then be assumed that in the two condensers the same field strength prevails at the separating film of the electrolyte. Since however $V_2 = 2\ V_1$, d_2 must be 2 d_1 and hence also the capacity of the second condenser half as great as that of the first. With an anode rated for 500 volts the thickness of the oxide layer is 0.6 μ.

Thus with the same area of aluminium we can make a condenser with e.g. a rating of 10 μF at 500 volts, 20μF at 250 volts, 50 μF at 100 volts, etc. One of the principal advantages of the electrolytic condenser is that the thickness of its insulating layer is automatically matched to the potential difference.

Disruptive Voltage of Electrolytic Condensers

Mention has already been made of the fact that sparking occurs with an electrolytic condenser when a certain critical potential difference is applied to it, such sparking being analogous to the breakdown of the dielectric in a standard condenser.

It is observed that this sparking voltage V is determined by the specific resistance (ϱ) of the electrolyte, and for a particular thickness of film is given by the expression:

$$V = a \log \varrho + b$$

where a and b are constants.

The increase of V with ϱ may be interpreted as follows: The greater the concentration of the ions in the electrolyte, the greater will be the current emanating from the electrolyte, and hence the greater the number of electrons migrating to the dielectric, and the easier will breakdown (sparking) develop.

Theoretically therefore condensers with a very high disruptive voltage can be produced by making the specific resistance ϱ of the electrolyte sufficiently great. But the need for none too high a series resistance compels a compromise to be met, as already indicated when considering the dissipating current.

That the condenser does not suffer permanent deterioration from sparking has already been indicated, and this is still the case when the applied over-voltage is very high. While in this case the dissipating current is indeed higher, it yet assumes its normal value again with a normal working voltage soon after being overloaded.

Effect of Temperature on an Electrolytic Condenser

The temperature primarily affects the conductivity of the electrolyte, which rises with the temperature so that the series resistance R diminishes. With temperature increase the density of the free ions and their mobility also increase, resulting in an increase in the dissipating current. Between 20 and 60 °C this current becomes about three times greater, but is then still very small.

Electrolytic Condenser in Use

It has already been stated that the dissipating current continuously generates oxygen at the anode, the gas producing oxidation. The oxide film hence becomes thicker during the use of the condenser and the capacity diminishes. This decrease is however extremely small, since the dissipating current is itself low. Condensers having a liberal rating of 10 μF, after being in use for a year at 450 volts, have exhibited an average reduction in capacity of only 0.8 μF. The dissipating current and the resistance also remain practically constant.

When an electrolytic condenser has been taken out of service for a period of a few months, a fairly high current will be found to flow through the condenser during the first few seconds a potential difference is applied to it. The dissipating current drops very rapidly however, becoming small after a few minutes, and shortly after regains the value which it had when the condenser was taken off load.

Construction of Electrolytic Condensers

The electrolytic condensers made by Philips may be conveniently divided into three main groups differing from each other in construction as well as in their working voltage rating.

The most common type in use, which is termed the star type from the shape of the anode, is made for working voltages of 320, 350 and 450 volts. For working voltages of 500 and 550 volts a special high-tension type of condenser is made, while the socalled low-tension type is designed for working voltages of 25 and 12.5 volts. Details of these different types are given below, as well as some considerations which determined their specific designs.

1) Star Type *(Fig. 4)*

The anode in this condenser consists of a star-shaped aluminium electrode combining a large surface with a small volume. A method was developed in the laboratory for increasing the surface of the aluminium by chemical means (etching), as shown in *fig. 5*. By this etching process the initially smooth surface was roughened to such an extent that the active surface was enlarged several times. If aluminium treated in this way is prepared in the usual way, a capacity is obtained which on the average is seven times greater than that with a smooth surface. To this the compact dimensions of these condensers are due.

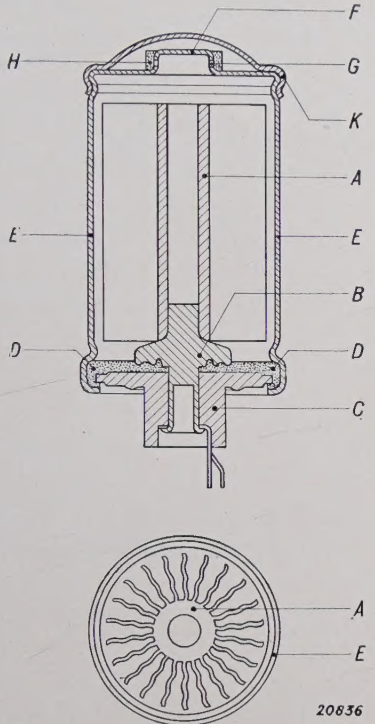


Fig. 4. Construction of a star-type electrolytic condenser. The anode *A* consists of a star-shaped aluminium rod. By means of the pin *B* the anode is rigidly connected with the "Philite" plug *C* which is threaded. The rubber gasket *D* provides a liquid-tight seal between the anode and the "Philite" plug and between the plug and the aluminium case (cathode). The aluminium sleeve *E* contains a valve at the top consisting of the bell-shaped extension *F* in the projecting wall of which holes *G* have been drilled. These holes are closed by the surrounding rubber band *H*. If the pressure in the condenser rises too far, pressure relief is obtained through the holes *G* along the rubber band *H*. The whole assembly is closed with the aluminium cap *K* which contains an absorbent material to take up any liquid trickling out of the valve. The sleeve is filled with electrolyte up to the edge of the anode.

The condenser case which also acts as the cathode consists of an aluminium cylinder closed at the bottom by a threaded "Philite" plug. This plug also serves for fixing the condenser and as an insulator for passing through the anode to the anode terminal. A rubber gasket giving a perfectly liquid-proof seal is inserted between the aluminium case and the "Philite" plug. The whole is filled with electrolyte of specific composition which differs according to the voltage rating. A valve is situated in the top of the aluminium case to allow the escape of gases evolved during service. It opens with an excess pressure less than 1 atmosphere. An absorbent mass is plugged round the valve to absorb any liquid trickling out through the valve, e.g. on high overloads; the whole assembly is closed by a cap.

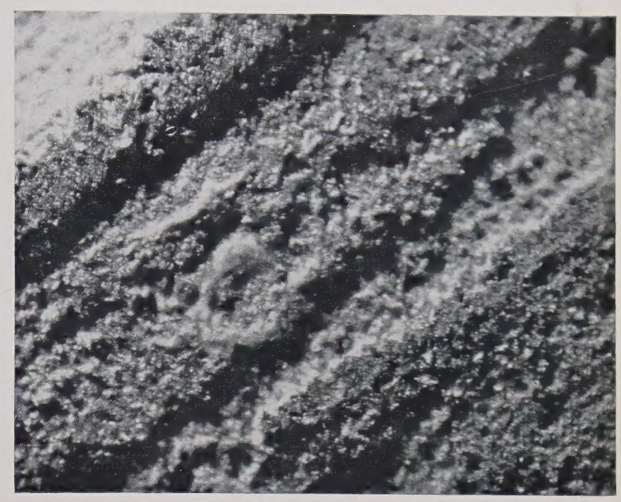


Fig. 5. Photograph of an etched electrode surface.

The following table gives the principal data relating to this type of condenser.

Table I

Capacity	8	16	32 μF
Max. working voltage . .	450	450	320 volts
Peak voltage	480	480	350 volts
Series resistance at 50 cycles and 20 °C.	ab. 70	ab. 45	ab. 10 Ω
Max. permissible alternating voltage at 50 cycles . .	23	23	16 volts
Max. dissipating current .	0.8	1.6	2 mA
Height	49	69	69 mm
Diameter	40	40	40 mm
Weight	90	125	125 g
Max. working temperature	60	60	60 °C

For this type of condenser the dissipating current is plotted against the potential difference in *fig. 6*. Since electrolytic condensers are mainly used to eliminate any A.C. component present in a unidirectional voltage (voltage smoothing in radio apparatus) the maximum permissible alternating voltage is also given in the above table. Care must be taken that in every case the direct voltage simultaneously applied is always greater than the amplitude of the alternating voltage, in other words the anode must never become negative with respect to the cathode. The working voltage in the table represents the sum of the applied direct voltage and the amplitude of the alternating voltage. The peak voltage is the voltage which can be safely applied to the condenser for short periods. It should be noted why an electrolytic condenser cannot sustain alternating voltages of unlimited magnitude. The alternating current flowing through the condenser makes the cathode, which is also of aluminium, alternately positive and negative with respect to the electrolyte. As already indicated above the aluminium becomes covered with an oxide film when it is positive with respect to the electrolyte. As a result this alternating current produces a capacity also at the cathode; this capacity is in fact very high, but as it is in series with the anode capacity it may reduce the total capacity. Experiments have shown that with an alternating current density of 0.5 mA per sq. cm (at 50 to 100 cycles) the cathode capacity remains so high after several thousand hours' service that no appreciable diminution of capacity takes place. By submitting the aluminium used for the cathode to special treatment it has been found possible to raise the permissible alternating current to from 4 to 5 mA per sq. cm (at 50 to 100 cycles). It may be noted that oxidation of the cathode ceases at frequencies above 500 cycles.

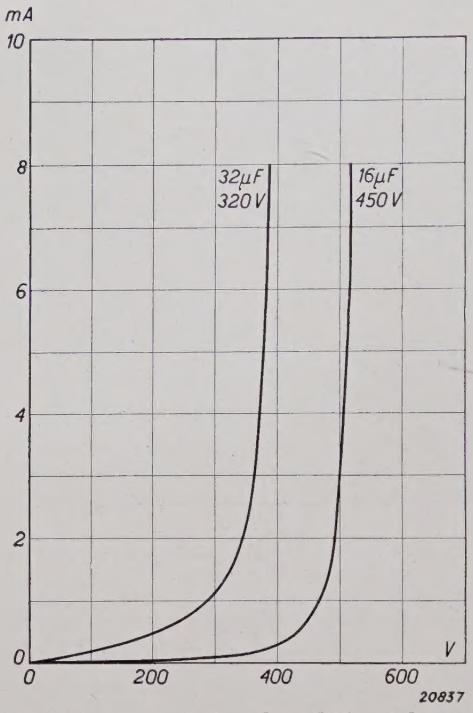


Fig. 6. Dissipating current of an electrolytic condenser plotted as a function of the voltage.

For this condenser type *fig. 7* shows the tangent of the phase difference (tan δ) at 50 cycles as a function of the temperature from —10 °C to 60 °C. The decrease in tan δ, or what is the same thing the drop in the series resistance, is due to the diminution of the specific resistance of the electrolyte with rising temperature. The dielectric losses in the separating layer are very small and can therefore be neglected in this connection.

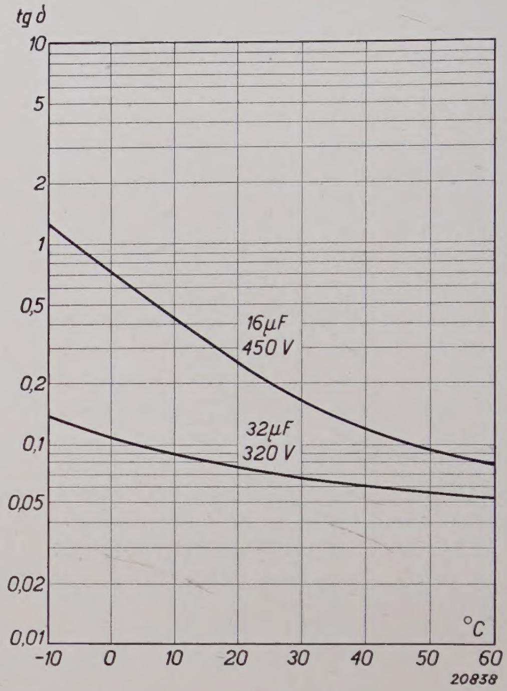


Fig. 7. Tangent of the phase difference (tan δ) at 50 cycles as a function of the temperature.

2) High-Tension Type

For working voltages of 500 volts and over, electrolytes must be used with a fairly high specific resistance (approximately 10 000 ohms per cm at 20 °C). An 8 μF condenser of the star-type would thus give a series resistance of 300 ohms and over, which is far too high. The only means available for reducing the series resistance is to make the distance between the anode and the cathode as small as possible, as has been done in the high-tension type of condenser (see *fig. 9*). The anode, which is a die casting, here consists of an aluminium cylinder which is surrounded internally and externally by the cathode placed at a distance of approximately 1 mm. The characteristics of this type of condenser are given in the following table.

Tabel II.

Capacity	8	8 μF
Max. working voltage	500	500 volts
Peak voltage	550	600 volts
Series resistance at 50 cycles, 20 °C	ab. 40	ab. 60 Ω
Max. A. C. Rating, 50 cycles	30	30 volt
Max. dissipating current	2	2 mA
Height	112	112 mm
Diameter	40	40 mm
Weight	115	117 g
Max. working temperature	50	50 °C

3) Low-Tension Type

These condensers are of similar construction to paper condensers; a cathode and an anode of thin aluminium foil are coiled together, being separated by a layer of paper impregnated with electrolyte, and enclosed in a compressed paper container; the two ends of the coil are compound sealed. The characteristics of this condenser are given in the following table:

Table III.

Capacity	25	50	μF
Working voltage	25	12.5	volts
Series resistance, 20 °C	ab. 6	ab. 6	Ω
Max. A.C. rating, 50 cycles	6	3	volts
Max. dissipating current	50	50	μA
Diameter	17	17	mm
Length	53	53	mm
Weight	14	14	g

Comparison between Electrolytic and Paper Condensers

The advantages offered by the electrolytic condenser over the paper condenser are as follows:

1) Higher capacity per unit of volume, especially at low working voltages; the oxide film can be made very thin by employing lower voltages during surface oxidation, while in the paper condensers a minimum thickness of paper is imperative.

2) While in the paper condenser surges may result in a breakdown of the dielectric and hence the complete destruction of the condenser, the electrolytic condenser can sustain overloads without damage, any disturbance being automatically made good.

The advantages of the paper condenser over the electrolytic condenser are the following:

1) No continuous e.m.f. for polarisation is required, so that there is no dissipating current.

2) Only the paper condenser can be used for a pure alternating current load.

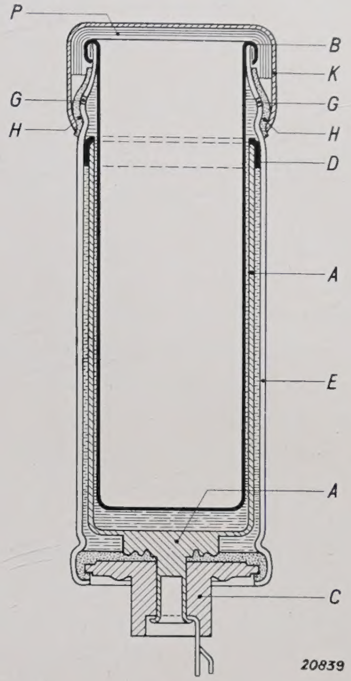


Fig. 8. Construction of a high-tension type of electrolytic condenser. The anode is a die casting and is shaped like an aluminium beaker closed at the bottom with the "Philite" plug *C* similar to that used in the star type of condenser. The cathode is made in two parts: one part constitutes the outer case of the condenser *E*, and the other an inner sleeve lapped at *B* to make liquid-proof contact with *E*. By adopting this construction the distance between the anode and the cathode is made very small. A strip of insulating material is fixed at *D* to facilitate the centering of the anode in the outer case during assembly. The valve again consists of a series of holes *G* in the outer container which are covered by a rubber band *H*. The valve is separated from the cap *K* by an intermediate layer of an absorbent material *P*.

3) The losses (tan δ) in the paper condenser are smaller than the electrolytic condenser, particularly at high frequencies.

4) For low capacity ratings (below 2 μF) the paper condenser is usually much cheaper than the electrolytic condenser.

In selecting a condenser for a specific duty these relative advantages and disadvantages must naturally be given careful consideration.

TELEVISION SYSTEM WITH NIPKOW DISC

By H. RINIA and C. DORSMAN.

Summary. A television transmitter suitable for transmitting films is described. By using a Nipkow disc, a secondary electron multiplier and a high-pressure mercury lamp a very simple layout of apparatus is achieved, as well as a high line frequency and excellent results in transmission. The electrical components of the system consist of two multipliers, a photo-electric cell and three amplifying valves.

Introduction

The possibility of using a revolving apertured disc for scanning television pictures was described by Nipkow already in 1884, and for a time a disc of this type was fairly extensively used for reproduction purposes. As the number of picture elements is however increased the difficulties of reproducing a satisfactory picture become serious so that at the present day the cathode ray tube is employed almost universally for reproduction.

It has nevertheless been found that the Nipkow disc can be used in a transmitting system with very good results in certain cases, as for instance for transmitting films up to a very high line frequency; its adoption also results in a marked simplification of the components required in the system. This applies in particular when a socalled multiplier tube is used as an amplifier and the high-pressure mercury lamp serves as a light source.

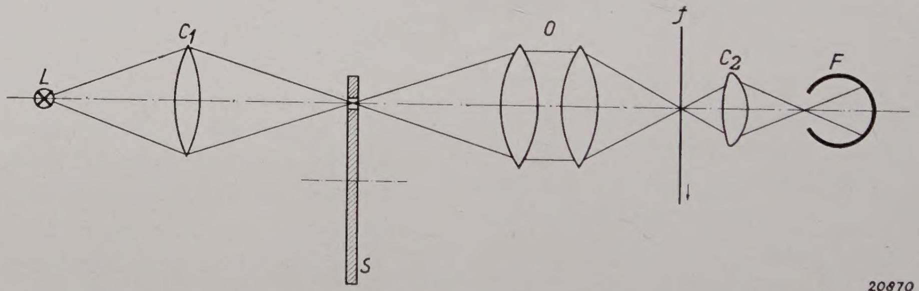


Fig. 1. Path of rays in film-scanning system using the Nipkow disc; L light source (high-pressure mercury lamp); C_1, C_2 condenser lenses; S Nipkow disc; O lens; f film; F photo-electric cell.

Description of the System

The path of the rays in the experimental television unit constructed at the Philips Laboratory is shown diagrammatically in *fig. 1.*

Close to the edge of the disc small holes are located at uniform intervals and at equal distances from the centre. The light from the elongated light source L is thrown on the perforated disc by the condenser lens C_1, in such a way that the line through the centre of the image touches the circle passing through the centres of the apertures. Part of the light thus passes through one of the holes and is projected on the film by the objective lens O. When the disc revolves the light spot sweeps out nearly a horizontal line on the film. The film is moved in a downward direction at a uniform velocity, so that the luminous line produced by the next hole on the film lies above the first line.

The objective lens O consists of two standard film-projection lenses with the sides, which in normal use are directed towards the screen, placed opposite to each other.

The use of two lenses requires in the first place the provision of a wide beam angle. The lenses are designed for use where the rays of the issuing pencil are roughly parallel and also accordingly corrected; such conditions in fact obtain in the Philips experimental transmitter. The disc and film are each situated at the focus of one of the lenses, and the scale of reproduction is determined by the ratio of the two focal lengths.

Finally, the transmitted light is condensed by C_2 and projected on to the photo-electric cell, where an electrical signal is produced, which after amplification is passed to the transmitter. It is apparent that the disc and film can be interchanged without any modification in the principle of the system or any diminution resulting in the maximum light intensity.

Potentialities of the disc

We propose to investigate the maximum amount of light which can be obtained for controlling the photo-electric cell.

Neglecting consideration of the absorption of the film, it is evident that the amount of light falling on the photo-electric cell is determined by the brightness of the lamp, the width of the aperture, the solid angle of the beam included at the disc, and the various losses sustained in the whole optical system.

If the brightness of the lamp is H, the solid angle of the beam passing through the hole Φ, the absorbed fraction of light a and the area of the hole o, the luminous flux incident on the cell is given by the expression:

$$H \cdot \Phi \cdot a \cdot o \quad \ldots\ldots \quad (1)$$

Brightness H

An elongated source of light with a high brightness value is required in the system under consideration; a very suitable illuminant for this purpose is the water-cooled high-pressure mercury lamp, which has a brightness value of 30 000 candles per sq. cm, or about three times the brightness of a standard carbon arc.

Solid Angle Φ

The solid angle Φ is limited by the capacity of the optical system, in fact by that lens of the two forming the compound objective O which has the shortest focal length. In our present system this is the lens on the side nearest the disc, so that an enlarged image of the disc is thrown on the film. We have made use of a lens with an aperture of 1 : 2, i.e. $\Phi = 0.2$.

Size of Aperture o

For a given number of picture elements, the size of the aperture is related to the peripheral velocity of the disc at the location of the holes. The width of the holes d_s bears the same ratio to the width d_b of the picture element determined by the scanning method employed, as the velocity of the disc V_s to the scanning speed V_b which is similarly determined:

$$d_s = d_b \cdot \frac{V_s}{V_b} \quad \ldots\ldots \quad (2)$$

The peripheral velocity of the disc is however limited by the maximum stresses which the material can sustain and in the apparatus constructed at this Laboratory is approximately 130 m per sec at the periphery of the circle swept out by the holes. The size of the holes is then arrived at as follows:

In *fig. 2* the picture area to be scanned is reproduced; the ratio b/h will be termed β. Assuming that during scanning n horizontal lines are successively traversed and that each hole is a square of side h/n, i.e. with a width equal to the interval between two consecutive lines, we then have:

$$d_b = \frac{h}{n} = \frac{b}{\beta\, n} \, .$$

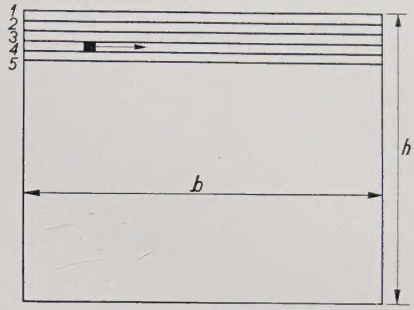


Fig. 2. Traversing of the exploring spot over the surface of the picture.

The total distance to be traversed by the aperture in scanning the picture is $n \cdot b$, i.e. the velocity V_b with N pictures per second is $V_b = N.n.b$.

Since $b = V_b/nN$, we have:

$$d_b = \frac{V_b}{\beta\, n^2 N} \, .$$

From equation (2) we thus get for the size of the hole the expression:

$$o = d_s^2 = \left(\frac{V_s}{\beta\; n^2\; N}\right)^2 \quad \ldots\ldots \quad (3)$$

This formula indicates that the size of the hole diminishes in inverse proportion to the fourth power of the line frequency, and that a high disc speed is desirable.

On inserting the following numerical values:

V_b = 13 000 cm per sec,
n = 405 lines per picture,
N = 25 pictures per sec, and
β = 1.2

we get:

$$o = \left(\frac{13\,000}{1.2 \cdot 25 \cdot 164\,000}\right)^2 = (2.64 \cdot 10^{-3}\ \mathrm{cm})^2 =$$
$$= 7 \cdot 10^{-6}\ \mathrm{cm}^2 \, ;$$

The length and width of the hole are therefore 26.4 μ. The total luminous flux according to equation (1), assuming that $\varrho = 0.5$, is therefore:

$$30\,000 \cdot 0.2 \cdot 0.5 \cdot 7{\cdot}10^{-6} = 2.1 \cdot 10^{-2}\ \text{lumen.}$$

If we assume that the sensitivity of the photo-electric cell for the light-source employed is 20 μA per lumen, the signal strength is found to be 0.42 μA, which as will be shown below is quite adequate.

If the holes in the disc were placed a greater distance apart than the width of the film, and hence the lens throws a reduced image on the film, the cone of light would have a greater solid angle on the side towards the film than on the side towards the disc. When therefore the maximum aperture obtainable with the optical system has been achieved on both sides, it is useless to increase the speed of the disc still further. In practice this limit is usually not reached when using standard film as well as a high line frequency.

Requisite Signal Current Intensity

The permissible minimum intensity of the signal current is determined by the fact that the signal during scanning a picture element must generate such a large number of electrons that the statistical irregularities of the photo-electric effect cannot cause any distortion. In the present case with $\beta . n^2 = 197\ 000$ picture elements the duration of scanning an element is:

$$\frac{1}{25 \cdot 197\,000} = 2 \cdot 10^{-7} \text{ sec.}$$

Since the charge of an electron is $1.6 \cdot 10^{-19}$ coulomb, the number of electrons liberated per picture element is:

$$0.42 \cdot 10^{-6} \cdot 2 \cdot 10^{-7} \div 1.6 \cdot 10^{-19} = 500\,000.$$

For the dark portions of the picture the number of electrons may be 40 times less. Yet in the case under consideration the number is always so large that the statistical deviations can be neglected.

Where, for instance, it is desirable to increase the number of picture elements, it is important to know how far the intensity of the signal current can be reduced. If the number of electrons emitted during scanning a single picture element with constant illumination is on an average a, it follows from the theory of least squares that this number varies on the average by $\sqrt{a}$; this places a lower limit to the number of electrons still of practical value. Assuming that in an area of the size of a picture element in the dark sections of the picture, fluctuations of approximately 20 per cent are still imperceptible, the minimum number of electrons is found to be 25. Where a maximum ratio of light to dark of 40 : 1 has still to be transmitted, this gives a total of 1000 electrons at maximum illumination. In the film-reproduction example worked out above the actual number is 500 times greater, so that in this respect a very liberal reserve is still available.

This favourable state of affairs is largely due to the exceptionally high brightness of the light source. If a system of this type were employed for direct scanning, the brightness values in the scanning room would have to be at least 10 000 times smaller, which would introduce considerable difficulties as regards the signal strength.

Amplification of the Signals

To operate a television transmitter the signal obtained in the manner described above must be amplified. In view of the still small strength of the signal currents, care must be taken that the method of amplification does not introduce its own specific distortion. For instance, the signal current could be passed through a resistance and the potential difference at the resistance terminals applied to the control grid of an amplifying valve. But in this case the thermal motion of the electrons in the resistance would produce fresh voltage fluctuations at the resistance terminals, which would be much greater than those due to current fluctuations in the photo-electric cell [1]). Moreover, the amplifying valve itself would introduce its own distorting effect. In spite of these difficulties amplification with receiving valves has yet proved quite feasible in the present system.

An amplifier designed on entirely different principles, viz., the secondary electron multiplier, offers in every respect a very great improvement as well as a simplification in design. This multiplier is briefly described below (*fig. 3*).

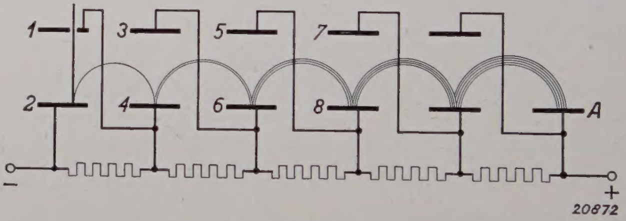


Fig. 3. Diagrammatic sketch of the secondary electron multiplier. A beam of light passes through electrode *1* on to *2* and at the latter causes the emission of photo-electrons. Under the action of the magnetic fields perpendicular to the plane of the paper and the electric fields between the different electrodes, the electrons are forced to move in the manner indicated. Each electron impinging on the electrodes *4*, *6*, *8*, etc., liberates further secondary electrons from these electrodes, so that *in toto* each photo-electron causes about 100 000 electrons to reach the anode A.

---

[1]) The voltage fluctuations due to thermal motion increase with the square root of the resistance, while the voltages generated by the signal current increase in direct proportion to the resistance. By increasing the resistance, the temperature effects can be reduced, although there is a limit to this reduction due to the adverse grid-cathode capacity of the amplifying valve, which is in parallel with the resistance. With a capacity of 12 and a frequency of $3 \cdot 10^6$ cycles, the total impedance can never exceed e.g. approximately 4500 ohms.

A series of flat electrodes *1*, *2*, *3*, etc., are mounted in an evacuated bulb. Electrode *2* is photo-sensitive and is illuminated through an aperture in electrode *1*. The surfaces of electrodes *4*, *6*, *8*, etc., have been pre-treated in such a way that an electron impinging on them with an energy of, say, 100 volts causes the emission of, for instance, 3 secondary electrons. The electrodes are connected up in the manner shown in the figure. A suitable potentiometer ensures an equal potential difference between all pairs of electrodes, e.g. 100 volts.

A magnetic field is applied perpendicularly to the plane of the figure. The operation of the multiplier is as follows:

An electron emitted by the action of the incident light is attracted upwards by the electric field between *1* and *2*. The magnetic field at the same time draws it towards the right so that it impinges on the electrode *4* with a velocity corresponding to the potential difference between *2* and *4*. At this electrode three electrons are liberated, which are similarly directed to strike *6* and each again causes the liberation of *3* electrons at this electrode. This cumulative action continues, such that with a fairly low number of electrons a current amplification of e.g. 10^5 can be obtained. If a multiplier of this type is used the whole of the photo-electric amplifier can be dispensed with and the root cause of thermal fluctuations is completely eliminated. The whole process takes place with practically no lag, so that even the very high frequencies are transmitted without any attenuation. Since the number of secondary electrons is affected only slightly by the acceleration voltages, the multiplier is practically insensitive to small voltage fluctuations and hence not subject to disturbances. Reaction, which for instance in the case of amplifiers may result in an undesirable oscillation, can also be entirely neglected. Since the multiplier can equally well amplify direct current and alternating current, it is evident that this method of amplification is practically ideal for the present purpose.

Specific Constructional Details

Measured to the circle of holes the Nipkow disc is 35 cm in diameter; it revolves at a speed of 125 r.p.s. Thus for a line frequency of 405, 81 holes are required round the periphery of the disc. The interval between the holes is 13.5 mm, while the width of the film picture to be scanned can be a maximum of 23 mm. The disc is thus reproduced with an enlargement of 1 : 1.7.

The above calculation has been made on the basis of square holes. Thus in scanning, as opposed to reproduction, the shape of the holes is not of paramount importance. In practice round holes are quite satisfactory, and have a diameter roughly equal to the distance between the lines or slightly larger than this interval. The greater ease with which this type of disc can be made is more than compensated by the slight loss in light. In our system the diameter of the holes is 27 μ. It is absolutely essential for the holes to be all exactly the same size, as otherwise disturbing dark and bright lines will be produced in the picture.

To obtain a uniform definition over the whole area of the picture, the holes must lie in the same plane. The high centrifugal force (here 12 000 times the force of gravity) ensures that even if the disc is initially slightly bent it will always rotate perfectly flat. Furthermore to obtain a satisfactory picture, all holes, both in a tangential and in a radial direction, must be in their exact theoretical positions (permissible error 5 μ) as well as retain these positions during rotation of the disc. To reduce the effects of air friction, the disc is enclosed in a iron housing which is evacuated (a residual pressure of about 1 cm of Hg is sufficiently low).

The mechanism for transporting the film is very simple, as the film motion must be continuous. The film is drawn across the film gate by means of a sprocket rotated at a speed of 1500 r.p.m. through two gears by a small synchronous motor. Contrary to a standard projector, it is unnecessary here to provide a drive for the sprocket feeding the film to the gate. Sound scanning with sound films requires no special arrangements for maintaining a perfectly uniform film speed, in view of the continous film motion employed.

Further Amplification of the Signals

To pass the picture signals obtained through a cable to the television transmitter without distortion, they must have a voltage of the order of several volts. The end of the cable is terminated with its impedance (here approximately 100 ohms), in order to avoid reflections.

The maximum signal which the secondary electron multiplier used can furnish is about 2 to 3 mA. The circuit used for amplifying these signals is shown in *fig. 4*. The current from the multiplier flows through a resistance R_1 connected across the grid and cathode of the valve L_1. The signal voltage at the grid of the valve can therefore be raised by making R_1 large. For the reasons given in footnote 1) the magnitude of the resistance which can be used is however limited. It was found feasible in the present system to use a resistance of $R_1 = 2500$ ohms, when a maximum signal of 5 to 7 volts is obtained at the grid and — with a cable with an impedance of 100 ohms and an amplifying valve slope of 10 mA per volt — the same voltage at the terminating resistance of the transmission line. As shown in the circuit diagram, the valve is connected up as a D.C. amplifier.

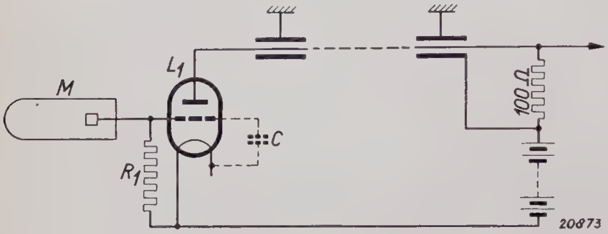


Fig. 4. Transmission of the picture signal generated by the multiplier to the television transmitter. The multiplier current generates voltages at the resistance R_1 which are ampified by the valve L_1; c is the adverse capacity of the valve and limits the frequency which can be transmitted.

Synchronising Signals

In addition to the picture signals, picture and line synchronising signals must also be transmitted (as to the form of these signals, see the articles by Van der Mark and Richards in this Review 2).

The synchronising signals are generated as follows:
A disc is mounted on the shaft of the synchronous motor which drives the film; it interrupts the beam of light between a lamp and a photo-electric cell, so that only during the time between two pictures does the light pass through a hole in the disc on to the cell. The cell current furnishes a signal which is amplified and which is applied to the line in the same way as the picture signal. The line synchronising signal is generated in the same way, using however the apertures in the Nipkow disc. Images of the holes are thrown by means of a second optical system on a fixed aperture behind which a secondary electron multiplier is again set up. It is apparent that in this way a short rectangular signal is produced. The circuit is in all other respects exactly the same as that for picture signal amplification. To suppress the line synchronising signals during picture synchronising, a revolving diaphragm is arranged in the path of the beam used for the line synchronising singals.

Apart from any supervisory apparatus required, two secondary electron multipliers, a photo-electric cell and three amplifying valves are employed to raise both the picture signals and the synchronising signals to the level required for transmission through the cable to the transmitter.

---

2) J. van der Mark, Philips techn. Rev. **1**, 325, 1936.
C. L. Richards, Philips techn. Rev. **2**, 33, 1937.

MAGNETIC CORES FOR LOADING COILS

By J. L. SNOEK.

Summary. Following a brief discussion of the technical reasons for the use of loading coils with magnetic cores, the characteristics of solid and subdivided cores are analysed with special reference to their use in loading coils. To avoid eddy current losses a subdivision by gaps in the direction of the field is necessary. Hysteresis losses and instability are considerably reduced by gaps perpendicular to the lines of force, but can also be brought down to the desired levels in the case of a nickel-iron alloy by suitable mechanical and thermal pre-treatment. In conclusion the magnetic state of this alloy is analysed more closely and the possible causes of its characteristic properties are discussed.

Magnetic Cores are Necessary for Loading Coils

The function of loading coils is to reduce the attenuation in telephone cables and at the same time make the attenuation independent of the frequency within the band of speech frequencies. As has already been shown in a previous article [1]), this end may be attained by raising the selfinduction of the line, provided the line resistance is not increased too much as a result thereof. The following equation was deduced in the previous article for the attenuation constant:

$$a = \sqrt{{}^1/_2 \sqrt{(R^2+\omega^2L^2)(G^2+\omega^2C^2)} + {}^1/_2 (RG-\omega^2LC)}, \qquad (1)$$

where L is the self-induction, R the resistance, C the capacity and G the dielectric conductivity, all expressed for unit length of the cable. This equation also applies for moderate frequencies when a part of the resistance and the self-induction are not uniformily distributed but are concentrated at loading coils situated at uniform intervals along the line.

An investigation will be made on the basis of equation (1) of the self-induction required in loading coils (and the permissible resistances) in order that these coils effectively reduce the attenuation at speech frequencies. To simplify this analysis G will be neglected compared to ωC (in practice G is approximately 1/10 000 ωC at speech frequencies) so that we get the simplified expression:

$$a = \sqrt{{}^1/_2 R\omega C} \cdot \sqrt{\sqrt{1+\frac{\omega^2L^2}{R^2}} - \frac{\omega L}{R}} \quad . \quad (2)$$

In a non-loaded line $\omega L \ll R$ for the speech frequencies, so that the second root of the equation (2) is nearly unity and hence $a = \sqrt{{}^1/_2 R\omega C}$. If $\omega L/R$ is increased, a becomes smaller, while if $\omega L \gg R$ we get to a first approximation:

$$a = \sqrt{{}^1/_2 R\omega C} \cdot \sqrt{\frac{R}{2\omega L}} = \frac{R}{2}\sqrt{\frac{C}{L}} \quad . \; . \; . \quad (3)$$

The attenuation is therefore reduced by the factor $\sqrt{2\omega L/R}$ and is independent of the frequency [2]).

To determine the requirements to be met by loading coils, the resistance is resolved into two components, viz., the component R_l due to the line and the component R_p due to the loading coil, as well as the self-induction neglected in the first case. We then have with $\omega L \gg R$:

$$a = \sqrt{{}^1/_2 \omega (R_l + R_p) C} \cdot \sqrt{\frac{R_l + R_p}{2\,\omega\, L_p}}$$

$$a = a_l\left(1 + \frac{R_p}{R_l}\right) \cdot \sqrt{\frac{R_l}{2\,R_p \omega}} \cdot \sqrt{\frac{R_p}{L_p}}, \quad . \quad (4)$$

where a_l is the attenuation of the non-loaded line.

The general specification as regards loading coils is that they must not raise the resistance of the lines by more than 15 per cent and they must also reduce the attenuation at 800 cycles to at least a quarter. Taking $R_p/R_l = 0.15$ we then have from equation (4)

$$a/a_l = (1 + 0.15)\sqrt{\frac{1}{2 \cdot 0.15 \cdot 2\pi \cdot 800}} \cdot \sqrt{\frac{R_p}{L_p}} \, .$$

If furthermore we put $a/a_l < 1/4$ we have: $R_p/L_p < 75$ ohms per henry.

---

[1]) W. Six, Philips techn. Rev. **1**, 357, 1936.

[2]) As was shown earlier (footnote 1), the attenuation is made entirely independent of the frequency when $LG = RC$. Since G is very small, this equation can generally only be satisfied in the case of telephone lines by providing a very high self-induction. Nevertheless, it is seen here that it is unnecessary to satisfy this condition. The attenuation is made sufficiently independent of the frequency if $\omega L \gg R$, which is in fact already the case in the speech-frequency range with much lower self-induction values.

If the attempt is made to build self-inductions with such low resistance values without introducing magnetic cores, the space required for the requisite cross-section of copper of each separate coil is found to be of the order of several cubic decimetres. Apart from the unnecessary waste of copper entailed, there is also the difficulty of finding accommodation for a large number of such coils in a buried cable box. In addition to the greater space requirements, air-core coils cannot be piled as closely as coils with magnetic cores, since their mutual interference is so much greater owing to their high leakage that cross-talking between one cable circuit to another results. To reduce the space requirements and the leakage of the coil it is imperative to raise the induction flux with the aid of magnetic cores, although these latter possess a number of undesirable characteristics as will be indicated below.

Distortion and Energy Losses with Magnetic Cores

If the air core of a coil is replaced by a magnetic core, the induction B, which in the air core is equal to the field intensity H, becomes multiplied by a specific factor; the same applies to the self-induction of the coil. The factor is termed the permeability of the core.

If B and H were exactly proportional to each other, i.e. if μ were constant, the coil would have exactly the same properties as an air-core coil, apart from its higher self-induction value.

But with solid ferro-magnetic materials the relationship between B and H is by no means so simple. In most cases the B-H curve is curved which results in non-linear distortion being produced. Moreover the relationship between B and H is not single-valued, since the induction in an alternating field with diminishing field intensity is on the average higher than when the field intensity is the same but increasing. This phenomenon which is termed hysteresis causes energy losses and also augments the non-linear distortion effects. A third undesirable property of the solid magnetic core is its electrical conductivity. The eddy currents induced in the iron represent an additional energy loss, which is exhibited as a resistance increasing with the square of the frequency.

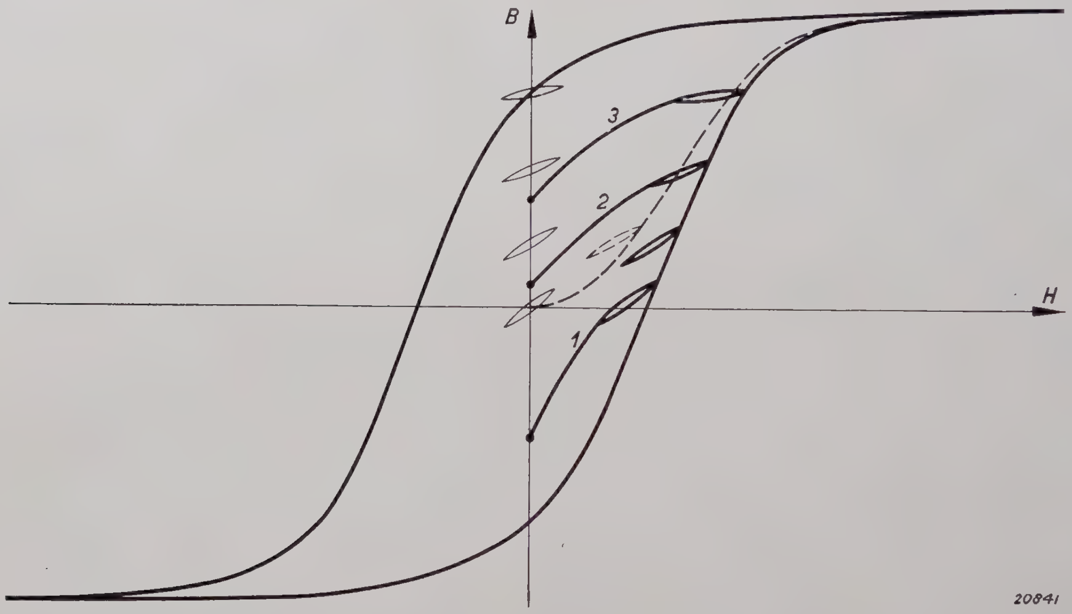


Fig. 1. Magnetisation curve of a hard magnetic iron. Depending on its magnetic history, every state can be realised corresponding to a point within the hysteresis loop. The small loops are traced out when the material is subjected to the same magnetic alternating field commencing from different points within the hysteresis loop.

Instability

The above discussion does not by any means exhaust the complex relationship between induction and field intensity shown in *fig. 1*. The first striking point indicated in the figure is that as the field intensity is raised the induction tends towards a saturation value. On reverse magnetisation different curves are traced out in the two directions, so that with a sufficiently high amplitude for the field intensity the lower loop in the figure is obtained.

If the field intensity is allowed to fall from smaller maximum values to zero, the induction values will follow the curves *1*, *2*, *3*, according to the initial values attained. Thus with a zero field a certain residual induction is retained.

The small loops at different parts of the diagram show the variation of induction when a weak alternating field is applied to the iron after submitting it to the afore-mentioned pre-treatment. The mean gradient of these loops is termed the *A.C. permeability*. This A. C. permeability differs in the different parts of the *B-H* diagram. R. Gans was the first to call attention to the remarkable fact that this permeability value is determined almost wholly by the magnitude of the induction and is only very loosely related to the field intensity. (The loops with the same ordinate in the figure are therefore parallel). In general the A.C. permeability is a maximum for $B = 0$, at first diminishing slowly with increasing induction and then more rapidly.

It follows from the above facts that the A.C. permeability in a zero field (which alone enters into consideration on practice) is determined by the cycles of pre-magnetisation, the effect being the greater the higher the residual induction. The resulting relationship between the self-induction of a coil and its previous magnetic history is termed its instability.

Improvement of Magnetic Cores

Efforts have been made in two directions to ameliorate the shortcomings of solid iron cores.

In the first place, an appreciable improvement in the characteristics of the core were achieved by suitably subdividing it by leaving gaps occupied by an insulating non-magnetic material. In this method marked differences are however observed between:

a) The effect of a gap parallel to the lines of force, and

b) The effect of a gap perpendicular to the lines of force.

As will be seen below, gaps running parallel to the lines of force cause a reduction in the eddy-current losses without the magnetic properties of the core being affected. The hysteresis losses and the instability can, however, be considerably reduced by putting the gaps perpendicular to the lines of force. No special requirements have to be met by the material of the core where this method is employed, except that it must have a maximum permeability.

It was furthermore found possible to reduce to negligible values both the hysteresis and the instability of the magnetic material by employing a suitable alloy and submitting it to suitable mechanical and thermal treatment. The gaps under b) above are then eliminated, while those under a) remain.

Gaps parallel to the Lines of Force

Fig. 2 shows a part of a core which is subdivided by parallel insulated gaps running parallel to the lines of force. The induction produced in the core at a specific field intensity is not affected by these gaps, so that they also do not influence the magnetic properties. On the other hand, it is readily seen that the eddy-current losses can be made as low as desirable by subdividing the core sufficiently. The path of the eddy currents is shown in the figure. When the induction B is sinusoidal relative to the frequency ω in radians, the peripheral voltage at the edge of each element of the subdivided core will be:

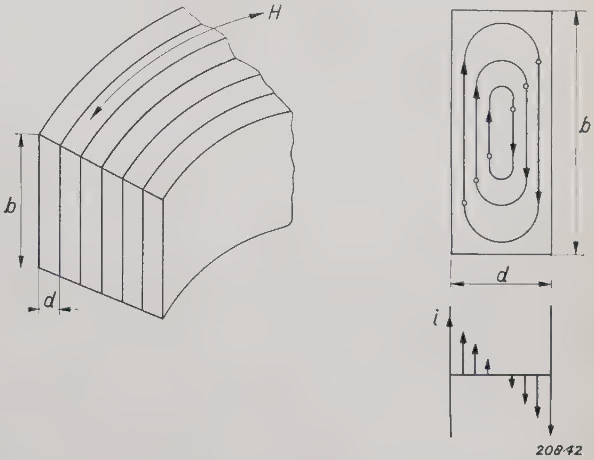


Fig. 2. Part of a coil core subdivided by gaps in the direction of the field H, which reduce the eddy currents. The diagram on the right illustrates the paths of the eddy current in a lamina.

$$u_{eff} = \omega\, B_{eff} \cdot d \cdot B \cdot 10^{-8} \text{ volt.}$$

The energy q developed per second in unit volume is however equal to the square of the electric field intensity divided by the specific resistance ϱ. The circumference is roughly $2b$, and the effective peripheral field intensity is hence $u_{eff}/2b$. We thus have:

$$q = \left(\frac{u_{eff}}{2\,b}\right)^2 \cdot \frac{1}{\varrho} = B^2_{eff}\,\omega^2\, d^2/4\,\varrho \cdot 10^{-16} \text{ watts/cm}^3.$$

Towards the centre the eddy currents become weaker and weaker, while the heat evolved also diminishes. A very simple calculation based on the current distribution shown in the figure indicates that the mean eddy-current losses per cub. cm are $^1/_3$ of the value calculated above. The losses thus increase with the squares of the frequency, induction and thickness of strip. By employing a sufficiently fine subdivision the losses can be reduced to a negligible and harmless amount.

It should be noted that a subdivision of the core into wires instead of into strips does not make for any considerable improvement. The eddy-current losses of a core made of strip material are only twice as great as those of a core made from wires with the same thickness.

Gaps Perpendicular to the Lines of Force

If the lines of force are intersected by gaps perpendicular to the field (as shown in *fig. 3)*, the induction is reduced as a result thereof. But a greater decrease is obtained in the instability and the hysteresis, so that by maintaining the self-induction constant the hysteresis losses can be reduced. This may be shown from fig. 3 by investigating how the induction in the core is determined by the mean field intensity H, i.e. by the number of ampere turns.

The field intensity in a sufficiently small gap perpendicular to the lines of force is equal to the induction in the magnetic material. For the mean field intensity we thus get, using the notation adopted in fig. 3:

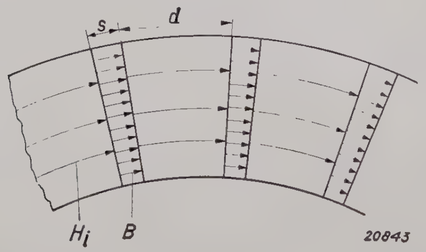


Fig. 3. Part of a coil core subdivided by gaps perpendicular to the direction of the field, which reduce the internal field H_i in the magnetic material and hence the hysteresis losses and the instability at a given mean field intensity of:

$$H = \frac{B_i s + H_i d}{s + d}$$

$$H = \frac{B s + H_i d}{s + d} \quad . \; . \; . \; . \; . \; . \; . \quad (5)$$

If the permeability of the magnetic material is sufficiently high, the induction B will be a multiple of H_i so that with a gap which is not too wide we have:

$$H_i d \ll B s \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (6)$$

We can then neglect $H_i.d$ in equation (5) without making a serious error, which gives the equations:

$$B = \left(1 + \frac{d}{s}\right) H, \; . \; . \; . \; . \; . \; . \quad (7)$$

i.e. a straight line relationship between B and H. The hysteresis and instability disappear and for the permeability we get independent of the properties of the material:

$$\mu = 1 + \frac{d}{s} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (8)$$

Actually the internal H_i field never completely disappears, so that a certain instability and hysteresis always remain. It may be readily seen that these effects will be the smaller, the greater the inequality (6) is made. It is thus possible to improve the inequality by increasing the ratio s/d, yet by doing so the permeability is reduced as indicated by equation (8). As a result the total losses in a loading coil increase again when the gaps s are made too large, for with diminishing permeability and given dimensions for the core and coil the number of turns required to arrive at a specific self-induction increases and hence the copper losses become greater. The total losses are a minimum when the iron losses are equal to the copper losses.

Compressed Cores

The system of twofold gaps described above has been realised in the socalled compressed iron powder cores or briefly compressed cores. These cores are composed of powdered granules which are moulded under pressure to the requisite shape with a non-magnetic binder. To avoid eddy currents the grains must be satisfactorily insulated against each other. A high permeability is also desirable, and requires the greatest care as regards the density of packing.

Finally it is desirable for the grains to be well rounded and free from sharp edges and corners, for at these irregularities high local induction values can be created in the material, thus introducing additional hysteresis losses. Moreover, irregularities in contour make effective insulation more difficult.

The degree of subdivision is not only of importance as regards the eddy current losses, for the ratio of the iron path to the gap path above determines the intensity of the hysteresis effects and not their absolute values. Yet if the gaps are too large stray fields and an assymetrical distribution will result, and these must be avoided at all costs in loading coils. By making the core of a compressed mass of small grains in which the stray fields can be neglected, a simple solution of this difficulty has been arrived at.

Loading-Coil Cores without Gaps perpendicular to the Lines of Force

It has already been reported in this Review that the Philips Laboratory has succeeded in improving the magnetic properties of a certain nickel-iron alloy by means of a combined rolling and heat-treatment process to such an extent that gaps perpendicular to the lines of forces are superfluous. The material therefore does not require pulverising, and to avoid the production of eddy currents it is sufficient to adopt the subdivision shown in fig. 2. To arrive at this result the loading-coil core is wound of a strip material, the surface of which has been electrically insulated by a coat of varnish. The permeability of the loading-coil cores made in this way is approximately 90, and is much smaller than with other kinds of soft iron, such as those employed for transformer cores, but yet double the value obtained with the compressed cores available at the time, so that the discovery of the new material allowed an appreciable reduction in the dimensions of loading coils. *Fig. 4B* reproduces a magnetisation curve of the new material in the direction of rolling, i.e. in the direction of the lines of force passing through the loading coil. This curve shows a very small remanence, so that since only small remanent induction values can be obtained a very low instability may be expected in view of the above-mentioned relationships between the A.C. permeability and the induction. The curve also shows that the relationship between B and H is linear over a wide range.

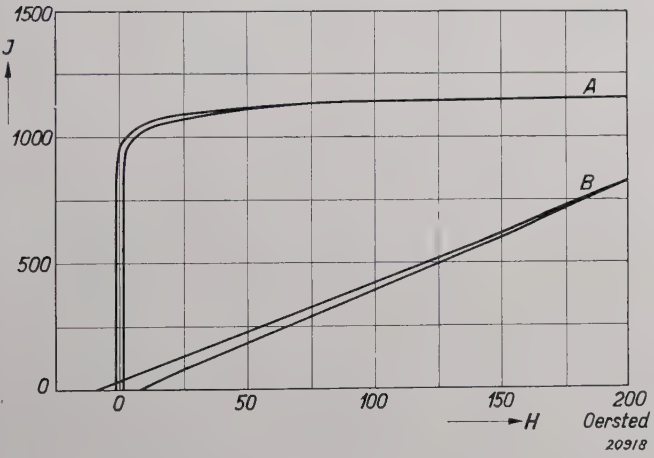


Fig. 4. Magnetisation curves for nickel-iron strip for loading coils.
A. Magnetic field perpendicular to the direction of rolling.
B. Magnetic field parallel to the direction of rolling.

An entirely different behaviour is shown by the curve when the direction of magnetisation is turned through 90 deg. in the plane of the strip. The magnetisation curve then obtained is of the type shown in fig. 4*A*, which, in contradistinction to the curve in fig. 4*B*, reveals an extremely high remanence (90 per cent of saturation) and a pronounced curvilinear relationship between B and H.

Measurements have confirmed the supposition that constant values for the A.C. permeability, instability and hysteresis have a much more undesirable effect on magnetisation in this direction that in the first case.

In the third principal direction, i.e. perpendicular to the plane of the strip, the magnetisation curve can only be measured if special precautions are taken, and is then found to be of the same type as the curve obtained in the direction of rolling (fig. 4*B*).

Magnetisation curves for directions other than in that of rolling have no practical significance, since magnetisation takes place exclusively in this direction. Particular interest attaches to them, however, for elucidating the magnetic conditions since they give an indication as to how the optimum properties are obtained in the direction of rolling.

We shall, therefore, make brief reference again to the general causes of remanent induction and hysteresis.

Causes of Hysteresis and Remanence

P. Weiss assumed that in ferromagnetic materials there is a force which compels the atomic magnets to take up the same direction in specific zones (*Fig. 5*). These Weiss zones are hence magnetically saturated; their individual directions of magnetisation are however in general quite haphazard, such that the body when viewed microscopically appears to be unmagnetised. According to Weiss the direction of magnetisation is capable

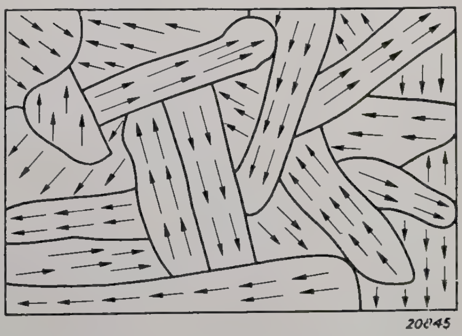


Fig. 5. Weiss zones. The unmagnetised iron is composed of submicroscopic zones which are magnetically saturated. The directions of magnetisation are however uniformly distributed such that the magnetised condition produces no external field.

of free rotation, the only restriction being that the prevailing direction must be the same for all atoms in each zone. If therefore a weak magnetic field is applied to the iron, the directions of magnetisation in all Weiss zones will be rotated in the direction of the field, with the result that the iron becomes immediately magnetically saturated.

There are indeed certain kinds of iron which exhibit this behaviour, while with other kinds powerful fields are required to obtain saturation. The reason for this was given by R. Becker, who demonstrated that the magnetisation in these materials is not devoid of directional control, but inseparately associated with certain preferred directions. This restriction to a preferred direction may be regarded as somewhat similar to the spring switch shown in *fig. 6;* the arrow on this switch has an equal tendency to point either to the left or right, and if moved into any inclined position will of its own accord jump back into one of these preferred positions.

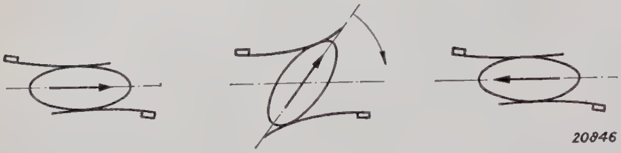


Fig. 6. Diagram of the forces acting on the arrow (which indicates the direction of magnetisation) where a preferred direction of magnetisation obtains. The magnetic induction can be directed either to the right or left and from any intermediate position tends to occupy either one of these directions.

The preferred directions as a rule will be entirely different for different zones *(fig. 5)*, yet the nature of hysteresis can be quite simply interpreted if it is assumed that there is only one preferred direction in a material. This state of affairs is shown in *fig. 7*, where the initial condition is unmagnetised. Half of the zonal magnetisation directions are towards the right, and those of the other half to the left. What will happen if a field directed to the right is slowly increased in intensity? As long as the field intensity is not high enough to overcome the elastic attraction to the preferred direction, the initial condition will be preserved. At a certain critical field intensity H_k the "switch" is reversed in direction from right to left, so that saturation is suddenly reached. If the field is again reduced to zero, the magnetic saturation suddenly changes sign, and thus gives the magnetisation curve *A* shown in fig. 7.

Consider the action of a magnetic field perpendicular to the preferred direction. In this case the directions of magnetisation will commence to rotate already with the weakest field strengths. But no reversals will take place. The directions of magnetisation of the different Weiss zones will rotate more and more in the direction of the field as the field intensity increases and will return in the same way to their initial positions on a reduction of the field, thus giving the magnetisation curve *B*.

With an arbitrary spacial distribution of the preferred directions, magnetisation will take place by the combination of rotations and sudden changes in orientation [3]). This aspect of the subject will not be discussed here, for the simplified model is indeed quite suitable for accounting for the magnetic properties of the strip material used for making loading coils, if it is assumed that the preferred direction of magnetisation in the plane of the strip is perpendicular to the direction of rolling. This follows from the close agreement between the diagrammatic curves in fig. 7*A* and *B* and the measured curves in fig. 4*A* and *B*.

In manufacture it is most important to know

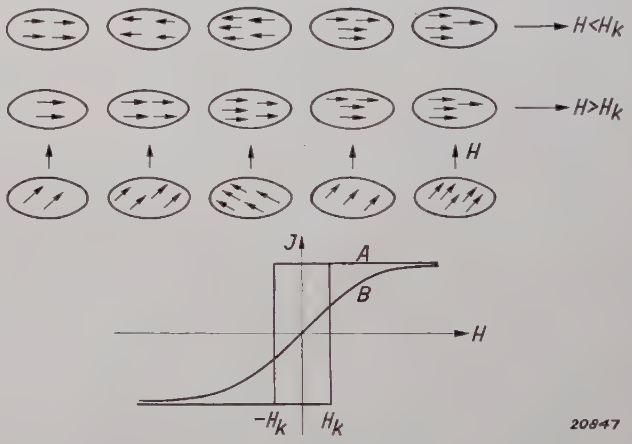


Fig. 7. Effect of a magnetic field on the induction, when in all Weiss zones the same preferred direction obtains:

A. Field in preferred direction; initial state unmagnetised, i.e. half of the magnetic arrows are opposite to the direction of the field. A magnetic field weaker than H_k has no effect. A magnetic field greater than H_k causes the opposing magnetic arrows to become suddenly reversed; the material becomes magnetically saturated and remains so also when the field is reduced (hysteresis).

B. Field perpendicular to the preferred direction. The magnetic arrows are rotated and no reversals take place. The material is therefore devoid of hysteresis and exhibits a slowly diminishing permeability with increasing field even when starting with weak intensities.

The curves *A* and *B* are the magnetisation curves obtained for cases *A* and *B* above. They are somewhat similar to curves *A* and *B* in fig. 5 and thus offer an explanation for the magnetic properties of the new loading-coil material.

---

[3]) Closer investigation of the sudden reversal process has demonstrated that the assumption that the Weiss zones are invariable in shape and size introduces too great a simplification of the actual conditions. Particularly with weak fields, magnetisation is mainly produced by the zones in a more favourable situation growing at the expense of the other zones.

how the preferred direction of magnetisation in question is produced, although much doubt still attaches to this point. Becker's theory advances two possible causes.

In the first place the majority of ferromagnetic substances have a preferred direction of magnetisation with reference to the axes of the crystals. In the cubic iron crystals, the three directions along the edges of the cube are preferred, and in nickel crystals which also have a cubic structure the four spacial diagonals.

Secondly, internal stresses may result in the appearance of new preferred directions; in the case of iron the direction of maximum tension is favoured, while in nickel that of maximum stress [4]). It is however difficult to determine whether one of these factors has a decisive influence on the magnetic properties of the new material or not.

At a first glance it appears as if the first factor has a direct bearing, since the preferred direction of magnetisation also has a crystallographic significance. With very limited scattering the crystals are so arranged that the axes of the cubes coincide with the longitudinal and transverse directions of the strip. On the other hand, the predominance of magnetisation in specific directions is too small in the crystals of this series of alloys (iron with 30 to 70 per cent nickel) for the order of magnitude of the observed phenomena to be determined. For a specific alloy of this series (65 per cent nickel) the different directions in the crystal are in fact completely equivalent from a magnetisation standpoint. Nevertheless this alloy after suitable pre-treatment also exhibits the same behaviour as the other alloys. The crystalline configuration is thus alone incapable of interpreting the magnetic behaviour, which in fact already follows from the fact that the extremes in magnetisation curves discussed above correspond to equivalent crystallographic directions.

The required magnetisation curve *B* is actually only obtained by a second rolling after arriving at the crystalline configuration by a first rolling and subsequent recrystallisation.The manufacture of this loading-coil material has been described and studied by means of X-rays, as outlined in an article published in this Review.

It should be noted that by a second rolling the position of the crystals is on the whole not altered, from which it follows that the conditions of shear are entirely different in such an "orientated" material to those in standard materials in which, after similar reduction by rolling, nothing remains of the original texture of the material.

The experience gathered in the manufacture of this material indicates that the peculiar distribution of stress occasioned by the specific shear characteristics is essential for obtaining the preferred direction of magnetisation perpendicular to the direction of rolling. The exact nature of these stresses has however not yet been fully established and it has not yet been possible to define a system of stresses which with the alloy in question here would result in the observed phenomena. It appears probable that entirely different and hitherto unsuspected conditions have a direct bearing on the magnetic properties of the material in question.

---

[4]) Actually the orientation of the stress with reference to the crystal axes is also an important factor. Cf. R. Becker, Phys. Z., **33**, 905, 1932.

AN APPARATUS FOR HYSTERESIS MEASUREMENTS ON SOFT MAGNETIC MATERIALS

By J. J. WENT.

Summary. To carry out hysteresis measurements on soft magnetic materials the specimen under investigation is preferably employed in the form of a closed ring which is placed in an annular magnetising coil. To insert the ring in the coil and to remove it from same, the coil is made in two parts which are joined in the plane of the ring and make contact while surrounding the ring specimen.

When plotting the hysteresis loop of a magnetic material, the relationship has to be found between the magnetic field strength H and the induction B. To determine this relationship it is desirable in every case to employ a method by which the field strength in the specimen under examination can be accurately calculated and kept absolutely constant, as otherwise it is not possible to obtain the value of the induction B corresponding to a specific value of H.

These two requirements are met by specimens in the form of an:

a) Ellipsoid, or a

b) Closed annular ring.

a) The ellipsoid is brought into a homogeneous field. The induction obtained can be determined by, for instance, measuring the deflection produced in a magnetic needle by the magnetised specimen under examination. An arrangement for this purpose has the advantage that it affords a homogeneous field of mathematical precision in the specimen and that magnetisation is easy to carry out. Against these points are the disadvantages that an ellipsoid is not easy to make; also difficulties accrue owing to part of the lines of force being through air. The latter is a particularly serious difficulty with soft materials, since these then exhibit a marked demagnetisation as a result of which the accurate determination of the field strength in the iron is rendered a very difficult operation. Moreover, measurements are very readily affected by external fields such as produced by the presence of iron or electric currents in the vicinity.

b) For this reason test specimens of soft materials are usually made in the form of a closed ring. The ring is then magnetised by a primary coil wound uniformly round it. The induction B is determined by measuring with a ballistic galvanometer the volt seconds (v sec) induced in a second coil on an alteration in the field strength. The following equation then applies:

$$B = \frac{\mathrm{V\,sec}}{f \cdot n} \cdot 10^8 \text{ Gauss},$$

where f is the cross-section of the iron and n the number of turns in the secondary coil.

The method of measurement described here has to meet the following requirements:

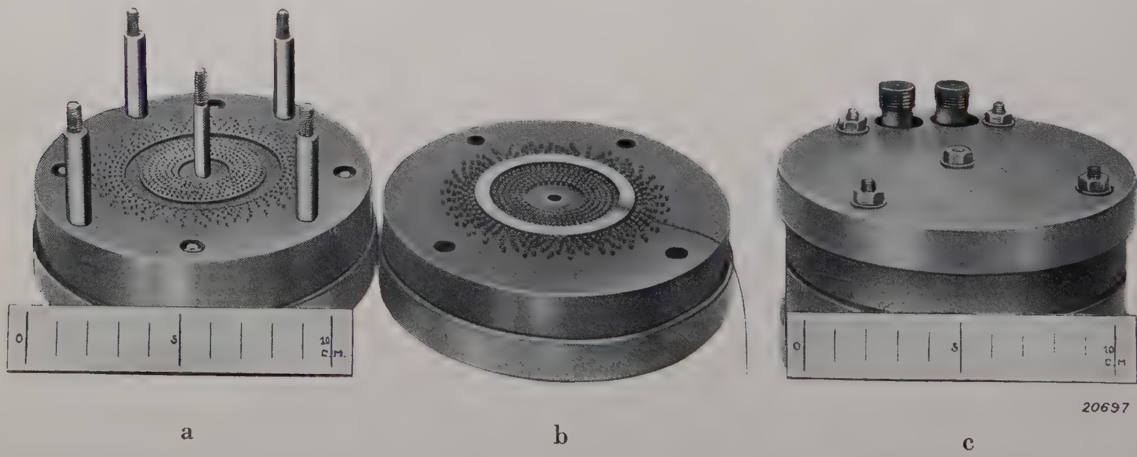


Fig. 1. View of two-part coil for carrying out hysteresis measurements. a) Top half, b) Lower half with iron ring, c) Two halves joined. In b) the small secondary coil wound round the iron ring may be seen.

1) The ring formed of the material under investigation must constitute a closed circuit; it must have no air gaps as otherwise demagnetisation may occur and hence the field strength not correspond entirely to the current through the primary coil and its number of turns.

2) The ring must have a uniform diameter throughout.

3) The internal circumference of the ring must be only slightly smaller than the outer diameter. If this condition is not met the field strength will not be adequately constant, since along every line of force $\int H\,ds$ = field strength × circumference has the same value.

4) The primary coil must be uniformly distributed over the whole ring.

In view of the first requirement it becomes impossible to make the core from several separate parts which are pushed into the coil individually, and hence each ring must be provided with a new set of windings. To avoid this tedious operation, a coil has been constructed in two halves and which can be fixed round the ring under examination (see *fig. 1*). Requirements 2 and 4 can be satisfied without difficulty. The ring is made of such dimensions that the maximum error under 3 above is 0.2 per cent, when the field strength is assumed to be that obtaining at the mean diameter of the ring.

Construction of Coil

Two ebonite discs A' and A'' (see *fig. 2*, right half) of 120 mm diameter and 20 mm thick are turned on a lathe leaving a wide flange at the sides by means of which the two parts can be rigidly joined together with four bolts C. Temporarily the fillers B', B'' and B''' are inserted between the two discs, B'' taking the place of the specimen which is later submitted to test. Both inside and outside B'' six series of 66, 60, 55, 45, 40 and 32 holes respectively of 1.5 mm diameter are now drilled along circles through the two plates. The holes are spaced at equal distances over the circles, so that on the inner circle a space of approximately 2 × 2 mm is available for each hole. A long enamelled copper wire (1.5 mm diameter) is now wound through all the holes, the windings nearest to B'' being made first. After completing each layer of windings the wire is again varnished and the surface then covered with a smooth coating of litharge and glycerine which very quickly hardens. When finally all six windings have been completed, the whole of the turned cavity of the disc is filled with this compound. The two discs are now closed with flat ebonite plates above and below, these being firmly screwed to the broad flange. The bolts are then removed and the whole assembly sawn through in the direction of the arrow. In the one disc all projecting copper points are smoothed down to conical points with a special hollow cutter (see fig. 1, left half), while in the other disc corresponding conical holes are drilled in the copper points. Naturally the fillers temporarily inserted are removed before these operations. If the discs are now again placed on each other, all 596 contacts can be simultaneously closed by tightening the nuts on the bolts. The contact resistance is so small that the resistance of the whole arrangement is about 1.5 ohms, this resistance moreover being found adequately constant. To ensure that the ebonite discs on tightening the nuts remain perfectly flat and the pressure is uniformly distributed over all contacts, two thick brass plates are inserted between the ebonite discs and the heads of the screws or nuts, as shown in fig. 1*c*.

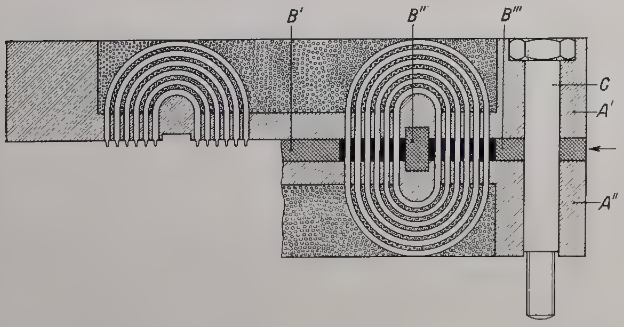


Fig. 2. Section through two-part coil, A' and A'' Ebonite discs, C Bolts, B', B'' and B''' Filler plates.

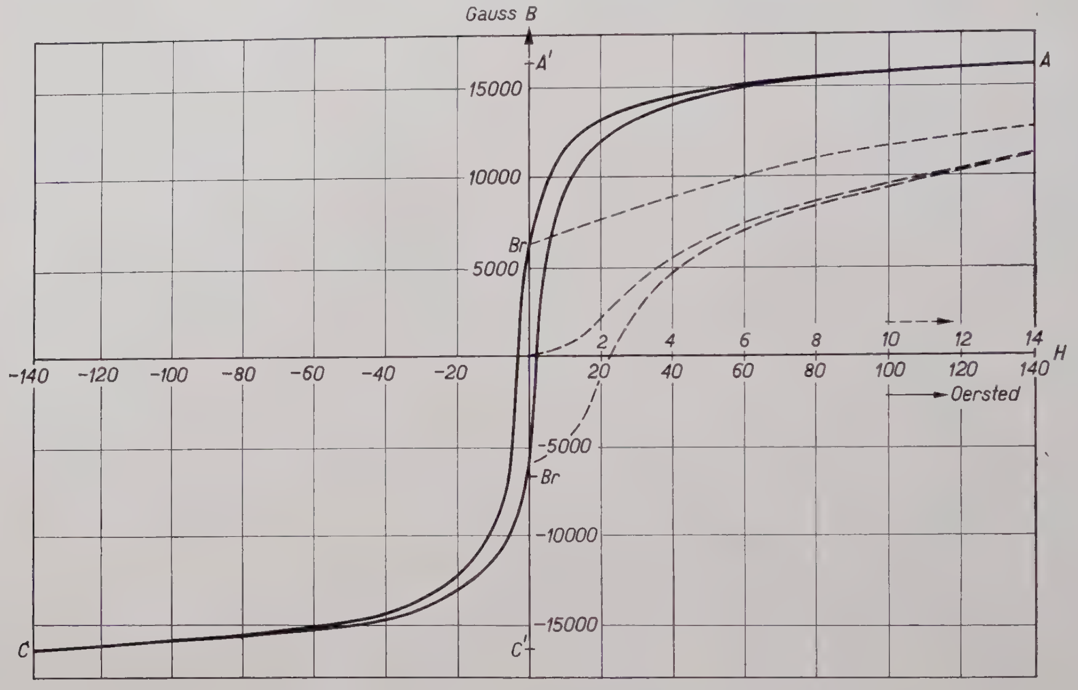
The heat generated by the current in the primary coil is very small owing to the low contact resistance. With a current intensity of 5 A, corresponding to a field strength of approximately 120 oersted, the temperature rise in the ring is about 1 °C. per min. It is therefore possible to carry out measurements also at very high field intensities, should this be found desirable.

For a measurement one or more rings of the magnetic material under investigation are made with an overall thickness of 4 mm and with internal and external diameters of 45 and 55 mm respectively. Three to ten turns of wire 100 μ thick to act as a secondary coil are wound round the rings being insulated by a layer of paper 10 μ thick, the number of turns depending on the thickness of the rings. The whole arrangement is placed in the coil, which is closed and is then ready for making ballistic measurements in the usual way.

At first such a powerful field is generated by passing a strong current (e.g. 6 amps) through the primary coil, that a magnetic condition is attained which lies outside the hysteresis region (e.g. *A* in *fig.* 3). If the current is then allowed to drop to zero again, the field H also becomes zero, while the ring retains the induction B_r, which is termed the remanence or remanent induction. The magnitude of this remanence can be obtained by direct measurement of the induction currents in the secondary coil,

a) By again applying a current of 6 A and measuring the change in induction B_rA';

b) By applying a current of — 6 A and again measuring the change in induction B_rC'.



20605

Fig. 3. Magnetisation curve for soft iron. The dash lines indicate the induction on a scale magnified 10 times.

We get directly from the graph the remanence $^1/_2$ $(B_rC' - B_rA')$ and for the magnetisation at a field strength of 6 A, $^1/_2$ $(B_rC' + B_rA')$. The other points of the hysteresis loop are obtained by starting from A and reducing the field intensity or starting from B_r and applying negative field intensities. It is assumed here that the hysteresis loop has the same form for both negative and positive field strengths.

If finally the virgin or initial magnetisation curve is to be traced the ring must first be completely demagnetised, which can be done by means of an alternating current of gradually increasing strength; the corresponding induction for the virgin curve can then be determined by applying a field of known intensity.

GLASS FOR MODERN ELECTRIC LAMPS AND RADIO VALVES

By J. SMELT.

Summary. Modern views regarding the nature of the physical state of glass are discussed. The viscous state is accounted for if the glass in this state is regarded as a polymerisation product comprising large molecular groups. The glass used for bulbs and the internal components of electric lamps and gas discharge lamps must conform to very close specifications. How these requirements are met and which factors have to be taken into consideration are discussed.

What is Glass?

Technically glass is a transparent solid material highly resistant to chemical attack, which in the fluid or viscous state can be worked to any desirable shape. It is usually manufactured from very cheap raw materials, such as sand, soda, lime, etc.

Physically glass is a supercooled liquid, viz., a solution of silicates in silicic acid. Recent investigations have, however, shown that this simple description does not entirely agree with the facts, and the hypothesis in now advanced that glass is subject to reversible transformation from and into at least three states of aggregation with change in temperature.

Above at certain temperature which for an ordinary glass ($Na_2O\text{-}CaO\text{-}6SiO_2$) is approximately 1200 °C., glass must be regarded as a liquid. This temperature is termed the transition temperature, and above it the crystallisation process termed devitrification in glass technology can no longer take place. The viscosity varies only slightly with temperature in this region, and is approximately 400 c.g.s. units. For the sake of comparison it may be noted that this value is ten times the viscosity of glycerine.

Below the transition temperature, the viscous state is situated, in which the viscosity varies in close relationship to the temperature, since for every increase of approximately 9 °C in temperature the viscosity is doubled. This marked change in internal friction is a characteristic of this state of aggregation, which may in fact be termed the fourth state of aggregation of matter. In this state devitrification can take place, other conditions being favourable, viz., if the glass is kept for some time in the viscous state. Small crystals gradually form in the initially transparent glass which increase to such numbers that eventually the glass becomes opaque.

It is assumed that the viscous glass on further cooling becomes increasingly viscid and very gradually passes over into the solid state of aggregation.

Various properties of glass, such as the viscosity, the thermal expansion and the electrical resistance, however exhibit anomalies between 500 and 600 °C. Most types of glass must be reheated to these temperatures after shaping in order to avoid mechanical stresses, which frequently develop on rapid cooling and cause the glass to crack. This temperature, which must be fairly accurately determined for each kind of glass, is termed the normalising temperature of the particular glass. The various anomalies observed indicate that at this temperature discontinuous changes take place.

Figs. 1a, b and *c* show the changes in a number of properties at various temperatures [1]), and brings out clearly the discontinuous changes at the normalising temperature. At still lower temperatures the viscosity of the glass varies only slightly. The tendency to devitrification has disappeared, the glass has become brittle and is very fragile, its properties being those we generally associate with ordinary glass.

These characteristics are assumed to be due to a polymerisation of the silicates, i.e. in the formation of molecular complexes. Above the transition temperature, ions alone are present, such as in ordinary liquid solutions, viz., Na^+, Ca^{++}, SiO_3^{--}, as well as molecules of SiO_2. But at the transition temperature the molecules and ions commence to combine to form higher polymers, such as:

$$SiO_2\text{ - }SiO_2\text{ - }SiO_2 \quad \text{and} \quad Ca < \begin{matrix} SiO_2\text{-}SiO_3^{--} = SiO_2 \\ SiO_2\text{-}SiO_3^{--} = SiO_2 \end{matrix}.$$

At the same time Na^+ ions remain. In the viscous state polymerisation gradually spreads until at the normalising temperature the Na-ions are also linked up at the polymerised molecule and only polymerised silicates remain. Contrary to the hardening of artificial resins, the polymerisation process in glass is reversible, such that a solidified glass can be reconverted to the liquid phase by transition through the viscous state.

---

[1]) Cf. Berger, Glastechnische Ber. **5**, 396, 1927: Beitrag zur Frage nach der Natur des Glaszustandes.

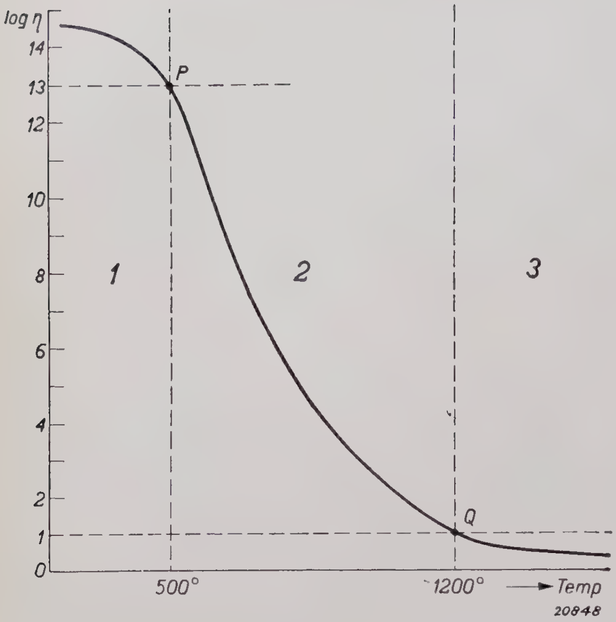


Fig. 1 *a*

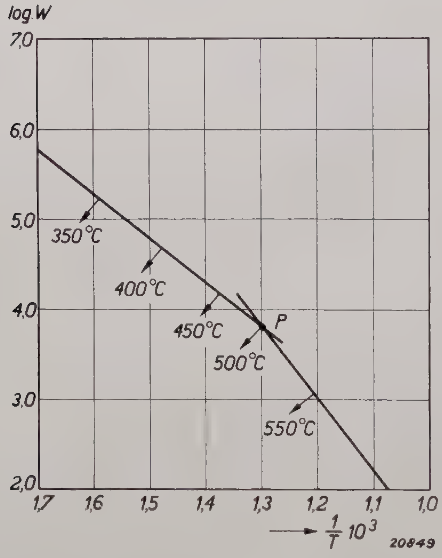


Fig. 1 *b*

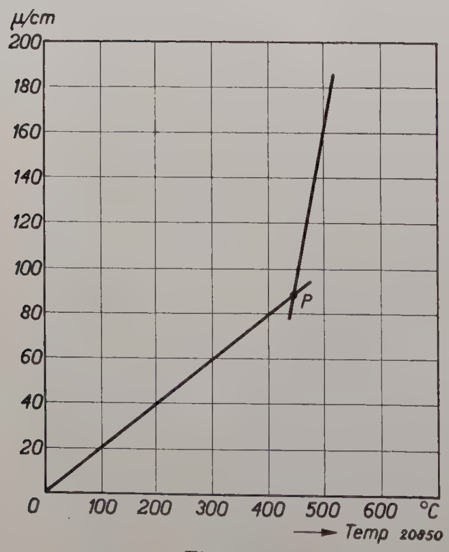


Fig. 1 *c*

Fig. 1. Curves of *a*) viscosity, *b*) specific electrical resistance W, and *c*) relative expansion in microns per cm, plotted as a function of the temperature (Temp. signifies °C, and T deg. abs.). In fig. 1*a*, *1* is the solid phase, *2* the viscous phase; *3* is above the transition temperature. The point P corresponds in all curves to the normalising temperature. In *b*) and *c*), which should be regarded as diagrammatic, the bends indicate that P is subject to abrupt changes. Actually the curves are continuous.

Before closer knowledge had been gained of the states of aggregation of glass, technical requirements made it necessary to produce different types of glass with specific optical properties, which led to the search for new oxides suitable for glass making. As a result of researches carried out to this end, the majority of the chemical elements are now employed in glass manufacture. Thus boric acid and phosphoric acid are frequently used in place of silicic acid, while the oxides PbO, K_2O, MgO, BaO, ZnO are also in common use. Fluorides which are difficult or impossible to dissolve and readily crystallise from solution are employed for making certain kinds of glass producing a dispersion of light. In addition, many metals, oxides, sulphides, sulphates and selenides are used for colouring glass or as auxiliary raw materials. The adoption of this wide range of new constituents of glass has enabled a large number of new glasses to be produced possessing specific optical, thermal, chemical and electrical properties.

Apart from the optical industry, no industry has gained more from the advances made in glass physics and technology than the electric lamp manufacturing industry.

In addition to a comprehensive knowledge of the properties of glass in the vitrified and viscous states (the rate of fusing the flanged stem tube to the lamp bulb is determined by the velocity with which the bulb can be heated without cracking, and by the time taken by the various components to fuse together), the electric lamp industry also requires a variety of glasses possessing different properties.

Electric lamps, radio receiving valves, X-ray tubes, mercury, sodium and neon lamps all require their own type of glass with well-defined properties. In electric lamp manufacture, the mechanical processes entailed require the glass to be easy and rapid to melt and shape. The use of these products in the Tropics necessitates a marked chemical resistance to moist heat. The action of sodium and mercury at high temperatures must not cause a deterioration of the glass used for these lamps. In view of the need for adequate insulation against high electric tensions, frequently at a distance of only a few millimetres, the electrical resistance has to meet strict specifications. Current leading-in wires of various types necessitate high or low coefficients of thermal expansion as the case may be. In addition different types of glass are needed which either transmit or absorb readily all waves in a specific wave band from the infra-red to X-rays.

Owing to the variety of technique employed in modern glass manufacture it has been possible to produce a suitable glass to meet almost every specific requirement.

The particular requirements from case to case are discussed below as well as the measures adopted to meet them.

Glass for Standard Electric Lamps and Receiving Valves

In glass for these products a distinction is generally drawn between that used for making the bulb and that for making the interior components of the lamp or valve.

The bulb glass must be cheap and hence made from inexpensive raw materials. Furthermore, it must have such a composition that it fuses readily at moderate temperatures without excessive wastage. It must also be adaptable to the modern mechanical methods of making electric lamp bulbs; it must fit the lamp base and give a close fused joint with ordinary flame heating. It must, moreover, be clear and in particular it must not devitrify or discolour when exposed for a comparatively prolonged period to the flame. It must also be satisfactorily resistant to moist heat.

Following this resumé of the essential requirements, it will be instructive if several points are discussed in further detail. As already indicated the raw materials from which glass is made are sand, soda and lime. The facility with which glass fuses can be measured by determining the softening point, i.e. the temperature at which the glass exhibits a specific viscosity. So that the viscosity of the glass is not raised too high, lime is in part replaced by barium oxide or magnesium oxide. Clear glass is made by using only pure raw materials free from iron. The tendency to devitrification is reduced by increasing the number of different components in the glass. The addition of Al_2O_3 also has a favourable effect in inhibiting devitrification. Although as a rule glass is highly weatherproof, its sensitivity to the action of water must not be underestimated, for during a long sea voyage in the Tropics glass which will remain unaffected in temperate climates will be found to have become completely weathered.

This action of water is due to the removal of the alkaline oxide from solution in the surface of the glass. This weathering action takes place in various stages, as follows:

1) Overall coating which can be readily removed with water.
2) Appearance of small crystals which as a rule cannot be removed by water.
3) The surface is more strongly attacked in certain localities; glass affected in this way can generally still be cleaned with hydrofluoric acid.
4) General and widespread attack of the surface, when the glass becomes quite useless; this occurs when the bulb has not been sealed during a sea voyage in the Tropics.

The first and second stages are due, as stated, to the action of water on the alkali contained in the surface of the glass, the carbon dioxide in the atmosphere forming Na_2CO_3 with the alkali. This carbonate in its turn dissolves the silicic acid in the glass (third stage), a process which spreads continuously (fourth stage).

The apparent contradiction that a finished lamp during a voyage through the Tropics undergoes no appreciable deterioration, while the inside of an open bulb is completely weathered, is due to the difference in the properties of the inner and outer surfaces resulting from the method of manufacture. Being polished by the influence of the flames the outside of the glass always exhibits a greater resistance than the inside surface.

Fortunately simple means have been devised to raise the resistance of the glass against atmospheric influences, viz., heat treatment of the bulb in an atmosphere of sulphur dioxide. By interaction of the alkaline oxide with sulphur dioxide and oxygen a thin coating of sodium suphate is formed on the surface of the glass, which can be readily removed from the bulb with water. The remaining surface, poor in alkali, has a greater resistance than the untreated surface.

If dilute hydrofluoric acid is allowed to act on the surface for a short time, the original composition of the glass is restored and the glass again exhibits its initial behaviour (see *fig. 2*). When bulbs which have been treated as described above are washed with hydrofluoric acid the greatest care must be exercised.

The requirements which have to be met by glass used in the interior components of lamps are as follows:

Since heat has to be applied externally for fusing the flanged stem tube to the bulb neck, the bulb becomes warm. Glass is therefore selected for the interior which has a low softening point in order that both the interior and exterior glasses soften at the same time. Usually the mounted foot is made of a glass with a fairly high content of lead, whose coefficient of expansion must be the same as that of the metal wires which are passed through the glass. Furthermore, as regards electrical properties, the glass used for the base must also satisfy certain requirements respecting conductivity.

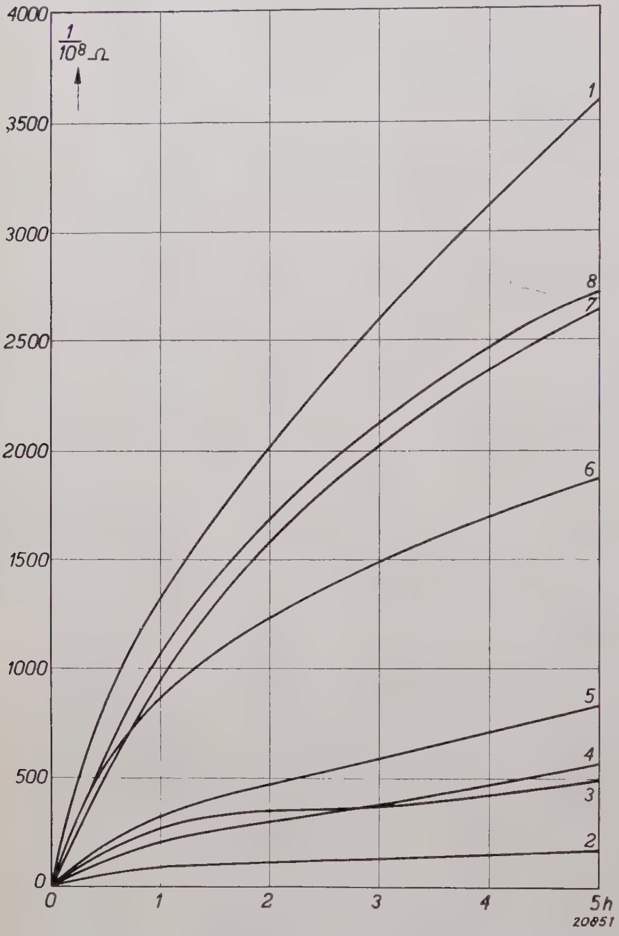


Fig. 2. Etching of glass bulbs after different pre-treatment. *1* - No pre-treatment, *2* - treated with SO_2 and rinsed out with water.
3 as *2* but treated with 3 per cent HF for $^1/_2$ min.
4 „ *2* „ „ „ 3 „ „ „ „ 1 „
5 „ *2* „ „ „ 3 „ „ „ „ 2 „
6 „ *2* „ „ „ 3 „ „ „ „ 5 „
7 „ *2* „ „ „ 3 „ „ „ „ 11 „
8 „ *2* „ „ „ 3 „ „ „ „ 18 „
The increase in the electrical conductivity of distilled water with which the bulb was filled for testing purposes over a period of 5 hours was taken as a measure of the degree of etching.

In general glass is one of the best electrical insulating materials. The electrical resistance W varies with the temperature according to the equation $\log W = B/T + A$, where A and B are constant for a specific composition. This equation is valid up to the normalising temperature. Above this temperature the same relationship applies with different values for A and B (cf. fig. 1*b*).

Conduction in glass is electrolytic, the current being carried by the alkalies and mainly by the Na-ions.

In radio valves and D.C. electric lamps socalled "lead trees" sometimes make their appearance at the negative pole after long use, together with fine cracks at the positive pole (*fig. 3*). Lead trees are black discolorations in the glass branching in all directions which appear in the direct neighbourhood of the pole wire. It is apparent from illustration why these frequently very variegated markings are termed trees.

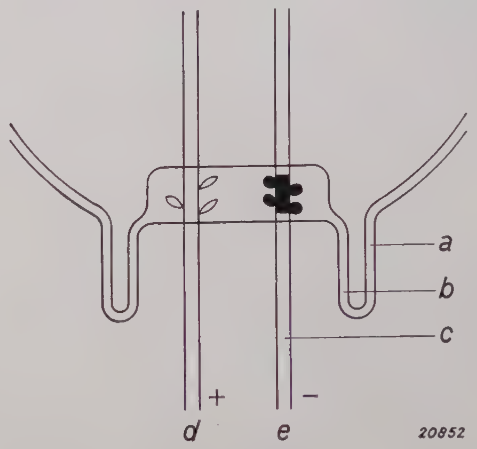


Fig. 3. Diagrammatic representation of the formation of lead trees in a D.C. electric lamp *a* bulb, *b*support, *c* lead-in, *d* cracks at positive lead-in, *e* lead tree at negative lead-in.

This phenomenon is obtained irrespective of the material of which the leading-in wire is made, whether of platinum, nickel-iron or chrome-iron wire, or dumet wire. Where sodium atoms are the current carriers, the positive pole must become reduced in sodium content. It is assumed that as a result a glass layer is produced which has a lower coefficient of expansion and is the cause of cracks appearing in the glass round the wires. At the negative pole, on the other hand, sodium is liberated and may lead to the reduction of the PbO in the glass to lead which builds up the lead tree. The amount of sodium liberated according to the electro-chemical equivalent, in a period of time of say 1000 hours, is however so small (with a current intensity of 0.1 μA approximately 0.07 mgr) that this action can hardly be held responsible for the cracking of the glass.

It has, however, been found that this phenomenon can be considerably reduced by using glasses with better electrolytic properties, i.e. glasses having a higher specific resistance at the temperatures in question.

The glasses with the best insulating properties are generally lead glasses which, in view of their low softening point, are also suitable for making lamp bases.

If in a particular lead glass Na_2O is replaced by K_2O or/and the PbO content is raised, a series of glasses is obtained with a considerably higher resistance and hence less liable to form lead trees or to crack. This alteration in the properties of the glass is readily explained by the fact that the mobility of the potassium ions is less than that of the sodiums ions.

Bulb Glass for Special Purposes

A. Opal Glasses. In these glasses the light is dispersed by devitrification or the precipitation of very small particles. The type of glass almost exclusively used at the present day is a cryolite glass in which the NaF particles crystallise out and disperse the light by diffraction. It is by nature more brittle than ordinary glass and is therefore used normally in the form of two layers the inner layer being ordinary glass.

B. Coloured Glass for photographic or illumination purposes. Coloured glass can be made by two processes:

1. By true (molecular) colouring with various coloured oxides, such as copper oxide, cobalt oxide, nickel oxide, chromium oxide or iron oxide.
2. By colloidal colouring.

While in the first process the glass solidifies in the coloured state from the viscous phase, glass coloured by the colloidal process must be submitted to subsequent heat treatment in the neighbourhood of the softening point, in order to render the submicroscopic particles visible. The media used for colouring include gold, selenium, cadmium sulphide (filter glass for motor-car and bicycle lamps), and copper (glass for darkroom lamps).

On the whole, glass technology has a very limited choice of colouring materials. In recent years the employment of the rare earths has enabled glasses to be produced which possess fairly sharp absorption bands at the same point at which the salts of these elements in solution exhibit sharp absorption lines. Thus e.g. neodymium oxide has an almost complete absorption in the yellow, although transmitting all other colours.

C. Hard Glass, which can be used for both bulbs and internal components.

If, for instance, the temperature of the filament in projector lamps is very high or the dimensions and construction are so restricted from practical considerations that the glass is raised to a very high temperature, the glass is liable to crack on switching on and off owing to the marked rapid temperature changes, or even become blown out following partial softening. The requirements which glass for these purposes has to meet are therefore:

a) The glass must have a higher softening point than ordinary glass; this as a rule can be obtained by reducing the alkali content.

b) The glass must be able to withstand considerable temperature changes; the thermal resistance is dependent on many factors of both a mechanical and thermal nature.

Winkelmann and Schott in 1894 by theoretical analysis deduced that the thermal resistance measured experimentally by suddenly raising the glass to a high temperature and then determining what temperature fluctuations it can withstand, depends on the following quantity F:

$$F = \frac{T}{a\,E}\sqrt{\frac{\lambda}{S\,C}},$$

where: λ = the thermal conductivity, T = the tensile strength, a = the coefficient of expansion, S = the specific gravity, E = the modulus of elasticity, and C the specific heat.

This equation has been found to be not quite accurate; yet the thermal resistance of glass is indeed mainly determined by the coefficient of expansion. The smaller this coefficient the greater are the temperature fluctuations which the glass can withstand. The raw materials which reduce the coefficient of expansion are SiO_2 and B_2O_3, while the alkalies cause a marked increase in this coefficient.

For the various oxides used in glassmaking, data have been gathered for the standard ranges of mixtures employed by means of which the physical constants of a glass, such as the coefficient of expansion, the modulus of elasticity, the specific gravity and the specific heat, can be calculated when the composition is known. These properties vary in general linearly with the amount of oxide added, a behaviour which is in good agreement with the assumption that glass consists of a solution of silicates in silicic acid.

The behaviour of the borosilicates is not however in accord with theory in this respect, since the coefficient of expansion does not vary with the percentages of the constituents. For instance in the case of a glass with a per cent Na_2O, x per cent SiO_2 and $(100—a—x)$ per cent B_2O_3 a minimum coefficient of expansion is found for a specific ratio of $SiO_2 : B_2O_3$. Similarly when the content of silica is kept constant, a pronounced minimum value is obtained for a specific ratio of $Na_2O : B_2O_3$.

This point has to be considered in determining the composition of a type of glass to be used for projector lamps which have to sustain heavy currents and high temperatures. The coefficeint of expansion has to be such that the glass always gives a tight joint with the metal wires fused through it, these wires being here of tungsten, molybdenum or iron nickel alloys.

Glass for Gas Discharge Tubes

The above considerations apply mainly to electric lamps with or without a gas filling and also to radio valves, in which stability at high temperatures (glass transmitting valves) is required in addition to good insulating properties of the glass.

Present day *gas discharge lamps* and *tubes* with their multitude of designs and types have introduced a series of new problems and requirements.

In the case of glass for *low-tension neon tubes* used for publicity and display purposes, the only condition requiring consideration is that the glass must not discolour in the blowpipe flame. This discoloration is due to the reduction of a number of oxides present in the glass, such as lead oxide, and the oxides of arsenic and antimony, which must therefore be avoided in glasses intended for these purposes. If *mercury* is added to the neon, the glass may become blackened after a time owing to the action of the mercury ions. Glasses with a relatively high electric resistance have been found by experience to be quite satisfactory for these applications. Lead glasses are also useful if they do not discolour in the flame, while barium glasses are exceptionally efficient.

Where it is a question of raising the efficiency of these light sources by transforming the ultra-violet radiation of the discharge into visible light, *fluorescent glass* may be used which usually contains a small quantity of certain metals, such as uranium.

An important problem is the transmission factor of glass for different wave lengths. Reference has already been made to the various methods employed in glass technology for improving or controlling transmission in the *visible spectrum*. The behaviour in the *ultra-violet region* is, however, also of importance. *Quartz* transmits the whole of the ultra-violet to 1850 Å. Different kinds of glass have also been produced which transmit a sufficient range of the U.V. radiation present in sunlight, while absorbing practically the whole of the shorter wave-lengths which have a deleterious action on the skin. One of the principal factors in making these types of glass is in fact a negative one, viz., the absence of iron and titanium; SiO_2, B_2O_3, P_2O_3 are the best oxides used in glassmaking which transmit U.V. rays. With low-purity glasses, i.e. those containing iron, the transmission factor becomes fairly rapidly diminished owing to the reduction of ferrous oxide to ferric oxide.

Nickel oxide glass is a glass which absorbs nearly all visible rays except the red. But it also transmits the longwave ultra-violet and again absorbs the short-wave ultra-violet rays. This glass is used in lamps for investigating fluorescence, where interference from visible light must be eliminated.

Ferro-glass, on the other hand, is bluish-green, has a marked absorption in the infra-red, and a low absorption in the visible spectrum. It is mainly used for absorbing heat rays.

In surveying the kinds of glass required for the transmission or absorption of *X-rays*, the well-known rule may be taken as a guide that the absorption increases with rising atomic weight of the constituents. The lighter the oxide used, the batter will the glass made from it transmit X-rays. Lindemann glass for instance is a lithium-beryllium borate. Glasses with a high lead content can, on the other hand, be used as a protection against X-rays, since they are impermeable to these rays.

The highly reactive element, sodium, which is used in sodium lamps, readily attacks ordinary silicate glasses with the result that in a short time the glass becomes brown owing to the reduction of the silica to silicon, and the light output is reduced in consequence. Boric acid offers a greater resistance to reduction than silica, and therefore borate glasses exhibit a greater resistance towards sodium than silicate glasses. Unfortunately these borate glasses are readily soluble in water and acids, so that they cannot be used for ordinary bulbs. They can however be used as enamels or in any other form as a thin coating on a bulb or a valve made of ordinary glass.

In the *high-pressure discharge tubes* with a mercury filling, the high pressures and temperatures obtaining require the glass to have a high softening point. The only kinds of glass of use for these purposes contain a high percentage of aluminium oxide and practically no alkali. A glass of this character can only be melted in the best furnaces, and the requirements to be met are at the limits of ordinary glass technology.

If the pressure of the mercury is still further raised, only one type of glass is available at the moment, viz., clear quartz glass.

Concluding Remarks

Glass must be free from its common defects, such as bubbles, streaks and grains, from considerations of appearance and to reduce the danger of cracking.

As indicated at the outset glass is shaped in the viscous state. The commonest method of making a glass bulb is by blowing into an iron mould, using either the mouth or machinery. This procedure makes it difficult to produce articles of a glass which has to conform to a specific composition. For by blowing, while the outer diameter is fixed, the inner diameter which depends on the amount and distribution of the glass used, is always somewhat uncertain. Every subsequent operation to which the glass must be submitted is difficult and tedious owing to the material's great hardness and brittleness, that it is advisable in making all glass objects to use only such designs in which the internal diameter can vary between wide limits. If the cavity is low and so shaped that it can be readily removed from a shaped die the shaping process can also be performed by pressing, when an exceptionally high standard of accuracy can be achieved.

PRACTICAL APPLICATIONS OF X-RAYS FOR THE EXAMINATION OF MATERIALS X

By W. G. BURGERS.

The example of the application of X-ray analysis discussed in this article shows how different physical states of one and the same material can be distinguished by X-rays; this is the same problem as was dealt with in the previous article in this series [1]).

22. Investigation of the Quality of Nickel-Iron Strip for Loading Coils

The material for making the cores of loading coils which has been evolved in this Laboratory consists of a thin strip of rolled nickel iron which is produced from the raw material (a strip several mm in thickness) by the following series of operations [2]):

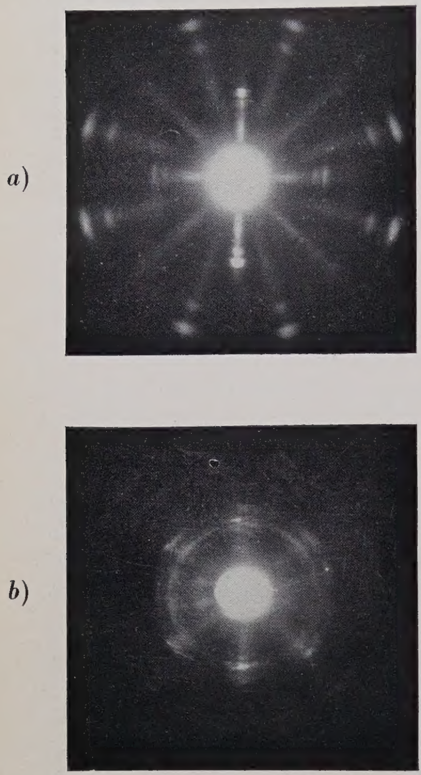
Raw material
(Strip several mm thick)
↓ Rolled to
a strip of 0.1 mm in thickness.
↓ Recrystallised at 1000 °C to give a
Recrystallised strip, 0.1 mm thick
↓ Rolled to
a strip 60 μ thick:
↓ Reheated at a temperature of approx. 400 °C.
Final product.

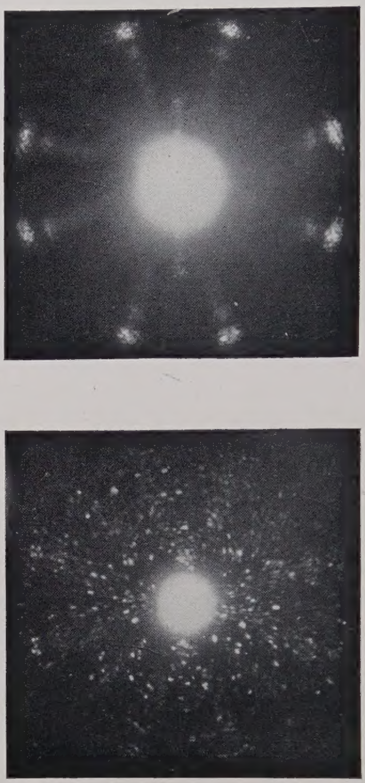
---

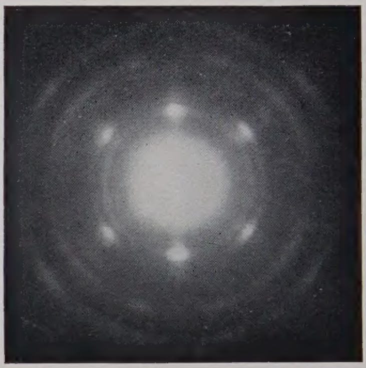
[1]) No. IX in this series of articles, Philips techn. Rev. **2**, 29, 1937.

[2]) Cf. the article by W. Six, Philips techn. Rev. **1**, 357, 1936.

After passing through this series of operations, a final product was obtained which exhibited very different qualities as regards the hysteresis losses. Since it was feasible that this was in some way related to differences in the orientation of the crystals in the material [3]), radiographs were produced of good and bad specimens of the material. regular and to a large extent symmetrical cubic configuration of points and lines indicates that the regular nickel-iron crystals are orientated in a very definite manner in the strip, such that a lateral surface of the elementary cube lies in the plane of the strip, while the edges of this lateral surface are parallel and perpendicular to the direction of rolling.







X-Ray Photographs of nickel-iron strip for making loading-coil cores during various stages of manufacture.

Fig. 1. **Final Product** *).

a) **Strip with low hysteresis loss:** Symmetrical cubical interference figure, due to a very marked preferential orientation of the crystals in the strip (socalled cubic configuration).

b) **Strip with high hysteresis loss:** Interference rings more or less complete; from this photograph it may be concluded that the crystals have not assumed a very pronounced preferential orientation.

Fig. 2. Initial material rolled to 0.1 mm and recrystallised subsequently:

a) On further rolling this material furnishes a strip with a low hysteresis loss (cf. fig. 1*a*.)

b) On further rolling this material furnishes a strip with a high hysteresis loss (cf. fig. 1*b*). At this stage also the X-ray photographs of the two materials differ in the same way as those for the final products.

Fig. 3. Initial material rolled to 0.1 mm and **not** yet recrystallised. At this stage the material gives a radiograph of the type illustrated, irrespective of whether on further working a loading-core material with a high or with a low hysteresis loss is obtained.

---

*) In all diagrams the direction of rolling is horizontal.

Fig. 1*a* reproduces a radiograph of a final strip with satisfactory properties. In making this picture the radiation impinged on the strip in a direction perpendicular to the surface so that the plane of the strip was parallel to the X-ray film. The direction of rolling is horizontal in the picture. The very Close examination of the picture shows that the crystals are closely packed about the cubical configuration.

That the cubic configuration is important as regards the magnetic properties of the loading-coil strip is shown in fig. 1*b* which reproduces a similar radiograph for a material with a high hysteresis loss: the interference rings are more or less uniformly blackened round the whole periphery, so that a predominating orientation of the crystals can only be assumed to obtain to a very slight degree: in any case the orientation differs entirely from that of a cubic configuration, which is indicated by the absence of any trace of a symmetrical cubic structure in the picture. It thus appears highly probable from the radiograph that the striking magnetic properties of the material are related in some way to a specific predominating orientation of the crystals.

---

[3]) Cf the article by J. L. **Snoek** in this issue of the Review, p. 77.

It was important to determine at what stage in the finishing process this cubic configuration is obtained, and for this purpose radiographs were made of the material at intermediate stages. It was found, in the first place, that the same patterns were given by a 60 μ strip which had not been reheated, as by the final product, which result is not surprising since the temperature at which reheating was conducted was too low for any new crystals to be formed.

The X-ray photographs obtained with a strip rolled to 0.1 mm and then recrystallised at 1100 °C are reproduced in *figs. 2a* and *b*; fig. 2*a* relates to a material which on further working gave a strip with a low hysteresis loss comparable to the type shown in fig. 1*a*, while fig. 2*b* is comparable to fig. 1*b* and gave a material with a high hysteresis loss.

It was observed that already at this stage the difference between the two specimens of material was unmistakable: Fig. 2*a* reveals a well-defined symmetrical cubic configuration, with the interference spots concentrated in groups to a still greater degree than found in fig. 1*a* for the final strip rolled out to 60 μ. The photograph thus indicates the occurrence of a definite cubic orientation in the recrystallised strip, which on rolling down to 60 μ does not lose appreciably in the definition of orientation, the general configuration being retained.

On the other hand, the spots in fig. 2*b* are distributed over practically the whole of the film (on a careful examination a trace of the characteristic cubic pattern of figs. 1*a* and 2*a* can still be detected): The crystals in this material exhibit practically no definite preferred positions.

At this stage it is hence possible to distinguish by means of X-rays between good material and bad material, and with a little practice the quality can be judged from the definition of the symmetrical cubic configuration revealed.

This cannot however be done at an earlier stage in manufacture, as is indicated by *fig. 3* which reproduces an X-ray photograph of the 0·1 mm strip before recrystallisation at 1100 °C In this stage the good-quality strip in figs. 1*a* and 2*a* gives practically the same pattern as the low-quality strip shown in figs. 1*b* and 2*b*, and a diagram such as that shown is always obtained irrespective of whether on further working a strip with low or high hysteresis losses is produced.

It is evident therefore that for the X-ray control of the manufacturing process the 0.1 mm strip after recrystallisation is the most suitable. Closer investigation has demonstrated that the cubic configuration is the more pronounced in this stage, the greater the difference in thickness between the initial material and the strip when rolled down to 0.1 mm.

It is a very striking fact that two substances which on X-ray analysis reveal no difference (cf. fig. 3), yet recrystallise quite differently on being subjected to the same heat treatment. This must be due to recrystallisation being determined by a property which is not revealed by the radiograph of the worked material. Probably the cause for this is to be sought in the formation of new crystals during recrystallisation at those points which have undergone maximum deformation (cf. e.g. the comments on this question made in reference to Example **20** in Part IX of this series of articles), such that the course of recrystallisation is closely related to the nature of deformation. At highly-deformed points of the lattice there will occur no or only the very slightest interference between the diffracted rays, and as a result it is possible that just these places in the deformed material do not appear in the radiograph; hence differences in the nature of the abnormalities, which may cause an alteration in the course of recrystallisation, need not become apparent in the X-ray photograph of the rolled material given in fig. 3.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS GLOEILAMPENFABRIEKEN

No. 1136*: R. Houwink: Synthetic Resins, their formation, their elastic and plastic properties and their possibilities (J. Soc. chem. Ind., **55**, 247 - 259, September, 1936).

This paper which was read before the annual meeting of the Society of Chemical Industry at Liverpool gives a survey of the methods of resin formation, with special reference to the following aspects:

1) The chemical nature of the reactions with a report of some results of recent investigations relating to the reaction kinetics;
2) The colloidal structure of the straight-chain and three-dimensional polymerides in their various stages of formation;
3) The plastic and elastic properties of resins in relation to their state of polymerisation.

An attempt is made to correlate the changes in elastic and plastic deformability with those in the colloidal structure of the resins, such correlation appearing possible in the light of current chemical theory regarding polymerisation reactions.

No. 1137*: J. R. J. van Dongen: Ermittlung der zulässigen Schnittgeschwindigkeit aus Plandrehversuchen (Stahl und Eisen, **56**, 1815 - 1187, September, 1936).

As full details have already been published in several previous issues of this Review of the results obtained in disk tests, reference should be made to these papers (Philips techn. Rev., **1**, 183 and 200, 1936).

No. 1138: R. Vermeulen: Modellen voor de studie van zaalacoustiek (Bouwkundige Bladen, **1**, No. 8, September, 1936).

Discussion of the application of optical models to the investigation of the acoustical properties of halls, of which details have already been published in Philips techn. Rev., **1**, 46, 1936, in reference to a hall in the Philips Theatre, is continued in this article with reference to the League of Nations building at Geneva.

No. 1139: J. A. M. van Liempt and J. A. de Vriend: Die Farbenwiedergabe beim Photographieren mit Natrium- und Quecksilberlicht (Photogr. Korresp., **72**, 142 - 144, October, 1936).

It is shown in this article how the already good reproduction of colours in photographs made with sodium light can be still further improved by suitable admixture of glowlamp or mercury light. (Cf. also Philips techn. Rev., **2**, 24, January, 1937).

No. 1140: P. J. Bouma: Verblinding (Natuur en Mens, **56**, 217 - 221, October, 1936).

For the subject matter of this article reference should be made to the previous papers by the same author published in this Review and relating to problems associated with roadway lighting (Philips techn. Rev., **1**, 102 and 225, 1936).

No. 1141: F. A. Heyn: Evidence for the expulsion of two neutrons from copper and zinc by one fast neutron (Nature, **138**, 723, October, 1936).

Bombardment of copper and zinc with neutrons gives rise to radio-active isotopes of these elements whose liberation cannot be accounted for by any of the known methods of nuclear transformation. From the behaviour of the particles emitted by these active bodies and from the fact that these reactions are initiated by fast neutrons, the author concludes that in the reaction investigated the expulsion of two neutrons takes place under bombardment with a fast neutron which is absorbed by the nucleus.

---

*) An adequate number of reprints for the purposes of distribution is not available of those publications marked with an asterisk *). Reprints of other publications may be obtained on application to the Director of the Natuurkundig Laboratorium, N.V. Philips Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.